The evolution of the Upper Ordovician to Silurian basin in the Condroz Inlier and the Brabant Massif from a litho- and biostratigraphical point of view

Jan Mortier

2014

Dissertation submitted for the degree
of Doctor of Science: Geology

Ghent University
Department of Geology and Soil Sciences
Supervisor: Prof. Dr. J. Verniers

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Fonds Wetenschappelijk Onderzoek
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Cover illustration: plate of two chitinozoans from the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville. On the left *Eisenackitina dolioliformis*, on the right *Lagenochitina* sp. 1.

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Abstract

Twelve years ago Verniers *et al.* (2002a) summarized what was known at the time about the Cambrian to Middle Devonian basin evolution and deformation history of Belgium, eastern England and surrounding areas east of the Midlands Microcraton. The combination of the data concerning the basin development, stratigraphy, sedimentology, subsidence history, magmatism, tectonic deformation and metamorphism led the authors to define three megasequences, each megasequence being characterized by a different geodynamic setting. In the present study only the third megasequence, starting in the middle Katian, is considered. This megasequence is heralded by the first signs of the collision, or better docking, of Avalonia and the continent Baltica. During the middle Silurian, these two continents collide with Laurentia. A counterclockwise rotation of the Midlands Microcraton with respect to the Lake District from the Caradoc (Sandbian-middle Katian) to the Emsian led to the convergence of the Midlands Microcraton and the Lüneberg-North Sea Microcraton, resulting in the Brabantian orogeny and the Anglo-Brabant Deformation Belt.

Stratigraphical data of the Condroz Inlier during the third megasequence are restricted, especially those for the Silurian part, this in contrast with our knowledge of the Brabant Massif. The data concerning the Condroz Inlier are mainly based on studies dating from the first half of the previous century. Some years ago, Vanmeirhaeghe (2006b), in his PhD study, revised the lithostratigraphy of the Ordovician and parts of the lower Silurian of the Condroz Inlier in combination with a biostratigraphy using chitinozoans.

Detailed field observations of the lithofacies in the Condroz Inlier led to the reconsideration of the lithostratigraphical units present in the inlier. Biostratigraphical analysis mainly with chitinozoans, but also with graptolites and brachiopods, allowed to place the lithostratigraphical units in the chronostratigraphy. Once the stratigraphy of the Condroz Inlier was established, correlation with the Brabant Massif became possible. During megasequence 3 the sediments of the Condroz Inlier were deposited on the shelf, but the location of the sedimentation on the shelf changed through time. During the same megasequence sedimentation of the Brabant Massif starts with shelf deposition, but slope conditions prevail during the Silurian with deposition of turbidites. The thickness of the lithostratigraphical units generally increases through the Llandovery with thick deposits starting from the upper Telychian. The basin of the Brabant Massif begins to deepen already in the upper Katian and we prefer to place the start of the development of the foreland basin at the onset of the deepening in the upper Katian.

From the lower Telychian on oxic-anoxic changes in the stratigraphical column of the Condroz Inlier are noted. From the upper Telychian on to the end of the Wenlock anoxic sedimentation takes place almost continuously, with deposition of dark grey, finely laminated mudstone; oxic intervals are limited. Such mudstone, known as laminated hemipelagites, have already been recorded from the Brabant Massif and are here described for the first time from the Condroz Inlier.

Dutch abstract – Nederlandstalige samenvatting

Twaalf jaar geleden vatten Verniers *et al.* (2002a) de toenmalige kennis samen van de bekkenevolutie en vervormingsgeschiedenis van België, oostelijk Engeland en omgevende gebieden gedurende het Cambrium tot het Midden-Devoon. Drie megasequenties werden gedefinieerd dankzij het samenvoegen van de gegevens betreffende de bekkenontwikkeling, de stratigrafie, de sedimentologie, de subsidentiegeschiedenis, het magmatisme, de tektonische vervorming en het metamorfisme. Elke megasequentie komt overeen met een andere geodynamische context. De voorliggende studie neemt enkel de derde megasequentie, aanvangend vanaf het midden Katiaan, in beschouwing. Deze megasequentie begint met de eerste tekenen van de botsing tussen Avalonia en Baltica, juister gezegd een "docking". Gedurende het midden Siluur botsen deze twee continenten met Laurentia. Van het Caradoc (Sandbiaan tot midden-Katiaan) tot het Emsiaan draait het Midlands Microcraton in tegenwijzerzin ten opzichte van het Lake District. De convergentie van het Midlands Microcraton en het Lüneberg-Noordzee Microcraton geeft aanleiding tot de Brabantse orogenese met als resultaat de Anglo-Brabant Vervormingsgordel.

De stratigrafische kennis van de Condrozstrook gedurende de derde megasequentie is beperkt, vooral die van het Siluur, dit in contrast met de gegevens betreffende het Massief van Brabant dat veel uitgebreider is. Onze kennis van de Condrozstrook is hoofdzakelijk gebaseerd op studies uitgevoerd gedurende de eerste helft van vorige eeuw. Met zijn doctoraatsstudie bracht Vanmeirhaeghe (2006b) daar verandering in: hij herzag het Ordovicium en delen van het onder Siluur van de Condrozstrook op basis van een uitgebreide lithostratigrafische analyse en een biostratigrafie gebruik makende van Chitinozoa.

Een herziening van de lithostratigrafische eenheden van de Condrozstrook was mogelijk dankzij gedetailleerde observaties in het veld van de lithofaciessen. Een biostratigrafische studie voornamelijk met Chitinozoa, maar ook met graptolieten en brachiopoden, liet toe om deze eenheden in de chronostratigrafie te plaatsen. Eenmaal de lithostratigrafie van de Condrozstrook vastgelegd, kon een correlatie gemaakt worden met het Massief van Brabant. Gedurende de derde megasequentie vindt de sedimentatie in de Condrozstrook steeds plaats op shelf, hoewel de plaats van de sedimentatie op de shelf doorheen de tijd verandert. Gedurende dezelfde megasequentie begint de sedimentatie in het Massief van Brabant met shelf-afzettingen, maar vanaf het Siluur komen turbidietafzettingen voor op de helling weg van de shelf. Gedurende het Llandovery nemen de diktes van de lithostratigrafische eenheden toe met uitgesproken dikke afzettingen vanaf het boven-Telychiaan. Een verdieping van het bekken van het Massief van Brabant vindt plaats vanaf het boven-Katiaan. Daarom plaatsen we het begin van de ontwikkeling van het voorlandbekken met de aanvang van de verdieping in het boven-Katiaan.

Oxische-anoxische schommelingen komen in de Condrozstrook voor vanaf het onder-Telychiaan. Vanaf het boven-Telychiaan tot het einde van het Wenlock had nagenoeg continue anoxische sedimentatie plaats, met afzetting van donkergrijze, fijn gelamineerde mudstone; oxische sedimentatie gebeurde slechts beperkt. Dergelijke gelamineerde mudstones, gekend als gelamineerde hemipelagieten, zijn al aangetroffen in het Massief van Brabant en worden in deze studie voor het eerst beschreven in de Condrozstrook.

Acknowledgements

This PhD study would not be possible without the help of various instances and people. Without funding this research would not have even started. Hence I would take this opportunity to thank the Bijzonder Onderzoeksfonds of the Ghent University and the Research Foundation – Flanders (FWO – Vlaanderen).

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And finally I want to thank my girlfriend Charlotte Pieters. Life with a PhD student is not easy. But thanks to all her support, patience and love it was possible to finish this thesis and I am so grateful to her. I love her.

It is unavoidable to forget some people in this enumeration, my apologies, but their help is much appreciated. Thank you.

Jan Mortier
7 September 2014

PART I – Introduction

PART II – Sections of the Condroz Inlier and the Brabant Massif

PART III – Discussion

PART I – Introduction

1. Problem setting

The knowledge and the understanding of the Brabant Massif, its development as a basin and its litho- and biostratigraphical record is quite well known as a result of extensive stratigraphical, sedimentological, structural, petrographical and other studies (Verniers *et al.*, 2002a; Linnemann *et al.*, 2012; Herbosch & Verniers, 2013 & 2014). By contrast the knowledge of the Condroz Inlier is poor, especially that of the Silurian part. The stratigraphical scheme of the Silurian part of the Condroz Inlier, published in Verniers *et al.* (2001), is based on the extensive studies by Michot (1928, 1932a, 1932b, 1934, 1954, 1957). Later few studies focused on the Condroz Inlier. We have the studies of acritarchs by Martin (1965, 1966, 1969a, b, c) and Martin *et al.* (1970), four M.Sc. studies at Ghent University by Van Doorne (1975), Maes (1976), Rombouts (1976) and Vandevelde (1976) and the resulting publication of the last three MSc studies in Maes *et al.* (1978). In the late eighties and nineties of the previous century came the study of brachiopods and trilobites of the Upper Ordovician Fosses Formation (Sheehan, 1987; Lespérance & Sheehan, 1987); the study of new geological data from the region of Ombret (Hance *et al.*, 1991); the study of Ordovician trilobites in the Oxhe Inlier (Dean, 1991); the study of the graptolites and acritarchs of the Middle Ordovician Huy Formation (Servais & Maletz, 1992) and a sedimentological and palaeontological analysis of the lower part of the Fosses Formation (Tourneur *et al.*, 1993). From the end of the nineties on a reactivation of the study of the Condroz Inlier took place with a major focus on the Ordovician (De Geest, 1998; Billiaert, 2000; Vanmeirhaeghe, 2001a, 2001b, 2002, 2006a, 2007a, b; Valcke, 2001a, 2001b; Valcke & Debacker, 2002; Vanmeirhaeghe & Verniers, 2002, 2004; Debacker & Vanmeirhaeghe, 2007; Owens & Servais, 2007) culminating in the PhD dissertation by Vanmeirhaeghe (2006b). The latter reviewed and redefined the lithostratigraphy of the Ordovician and parts of the Llandovery of the Condroz Inlier. However, most of the main part of the Silurian of the Condroz Inlier remained unstudied and our knowledge of it is still based on the studies by Michot cited above.

The lithostratigraphical units of the Silurian formations as now accepted correspond to the "assises" described by Malaise (1900), Maillieux (1930) and Michot (1932b, 1954). The term "assise" stands for a stratigraphical unit distinguished by its lithological and/or palaeontological features. "Assises" are not defined following the recommendations of the International Stratigraphic Guide (Hedberg, 1976; Salvador, 1994). Verniers *et al.* (2001) are the first authors who use the term formation and define the lithostratigraphical units according to the mentioned recommendations. But these units need revision as the lithostratigraphical description of most of them are vague and need refinement.

The Condroz Inlier coincides approximately with the Variscan front zone. It was deformed first by the Caledonian (s.l.) Orogeny and later by the Variscan Orogeny (a.o. Fourmarier, 1931, 1939; Michot, 1928, 1932a, 1932b, 1934, 1954, 1979). Moreover the outcrops are often patchy, with as a result that constructing a stratigraphical column is difficult and the effort needs to be underpinned by very detailed litho- and biostratigraphical studies.

Several graptolite levels have been observed in the Silurian of the Condroz Inlier (Michot, 1932a, 1932b, 1934, 1954; Maes *et al.*, 1978). It enabled previous workers to place the lithostratigraphical units of the Silurian of the Condroz Inlier in the chronostratigraphy. But a revision of these graptolite levels and biozones is necessary; especially the *crenulata* Biozone as applied in the Condroz Inlier. This biozone appears to cover four biozones, formerly one, of which the *crenulata* Biozone is the lowest: from base to top, *crenulata-spiralis-lapworthi-insectus* Biozone.

2. Objectives

The aim of this study is to construct a model of the evolution of the basin of the Condroz Inlier and the Brabant Massif during the middle Katian to Silurian using litho- and biostratigraphy. It concerns the sediments deposited during megasequence 3 (Verniers *et al.*, 2002; Linnemann, 2012). A detailed knowledge of the litho- and biostratigraphy of the Condroz Inlier is indispensable to accomplish this goal. Hence we aim to revise the lithostratigraphy of the Condroz Inlier of the middle Katian to Silurian and attempt a formal reappraisal of the different units. A biostratigraphy of the Condroz Inlier using mainly chitinozoans but also graptolites will be established for the same interval. It will allow to place the lithostratigraphical units in the chronostratigraphy and allow comparison with the better known Brabant Massif. We will also try to infer the depositional environment of the different units on the basis of facies and the palaeontological data.

3. Methods

A first step to accomplish our goal is to set up the lithostratigraphy of the Condroz Inlier. The type localities of the formerly known stratigraphical units of the Condroz Inlier were visited, studied and sampled for chitinozoans. The sections of Neuville-sous-Huy are of particular interest, because these sections contain almost continuous outcrops exposing a large part of the Silurian of the Condroz Inlier. These sections allowed in many cases to construct stratigraphical logs, notwithstanding the structural complexity.

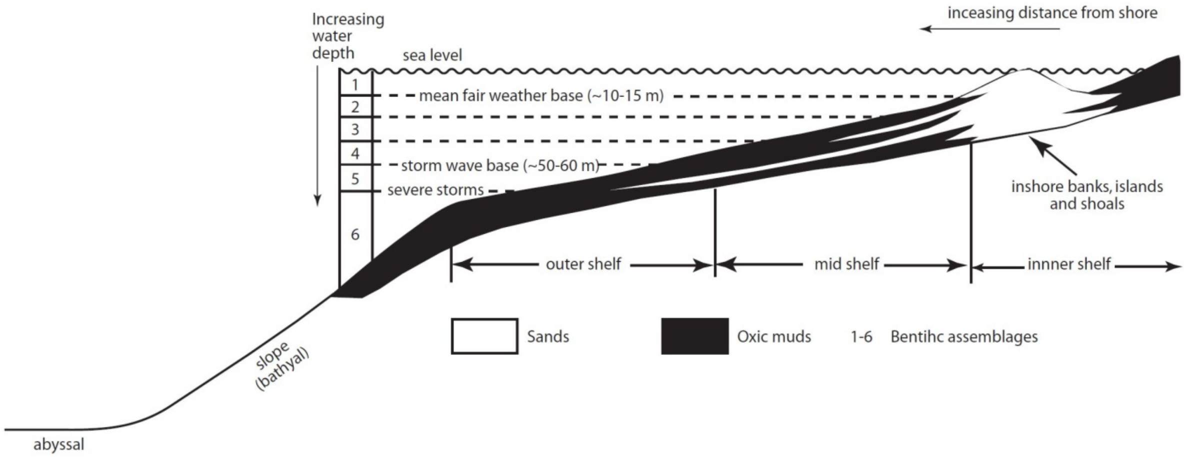


Fig. I.3.1. Schematic representation of benthic assemblages (BA) 1 to 6 following Boucot (1975), showing their relative position on a shelf and estimates of the BA 2-3 and BA 4-5 boundaries. After Vanmeirhaeghe, 2006b and originally from Brenchley & Harper (1998).

Sedimentology and fossils will be used to characterize the depositional environments. The fossils can contribute to identify the depositional environment. Ziegler (1965) developed the concept of depth-specific benthic communities, refined by Ziegler *et al.* (1968a), i.e., fossil communities can be used as a tool for the reconstruction of the depositional depth. This approach was further expanded by Boucot (1975) who introduced the name of benthic assemblage zones (BA) and defined six faunal assemblages (see fig. I.3.1.). Brachiopods collected during our research were sent to Prof. Dr. David Harper (Durham University, Durham, United Kingdom) and graptolites to Prof. Dr. Petr Storch (Institute of Geology AS CR, Prague, Czech Republic) and Prof. Dr. Jan Zalasiewicz (University of Leicester, Leicester, United Kingdom) for identification.

Chitinozoans are used as the primary tool for biostratigraphy because of their marked potential for correlation. Many chitinozoan species are short ranging, the average length of a biozone is generally 1 to 2 Ma for the Ordovician and the Silurian. Moreover they show a wide dispersal over large areas, caused by their planktonic to epiplanktonic life habits (Paris & Verniers, 2005), be it that they may be latitudinally constrained. Chitinozoans have the advantage that they occur frequently throughout the sections we studied. A prerequisite for findings chitinozoans is that the rocks are not too metamorphosed, heavily tectonised, oxidized or weathered; that is often not the case in our study area. Two fossil groups are traditionally used for biostratigraphy of Ordovician and Silurian rocks: conodonts and graptolites. The succession of the Condroz Inlier is mainly siliciclastic, hence conodonts are rare. Graptolites occur only in certain levels. Chitinozoans are hence the most useful fossils that can be used for biostratigraphy in the Ordovician and the Silurian of the Condroz Inlier and to place the lithostratigraphical units in the chronostratigraphy.

4. Overview of the knowledge of the Upper Ordovician and Silurian of the Condroz Inlier and the Brabant Massif

4.1. Condroz Inlier

4.1.1. Introduction

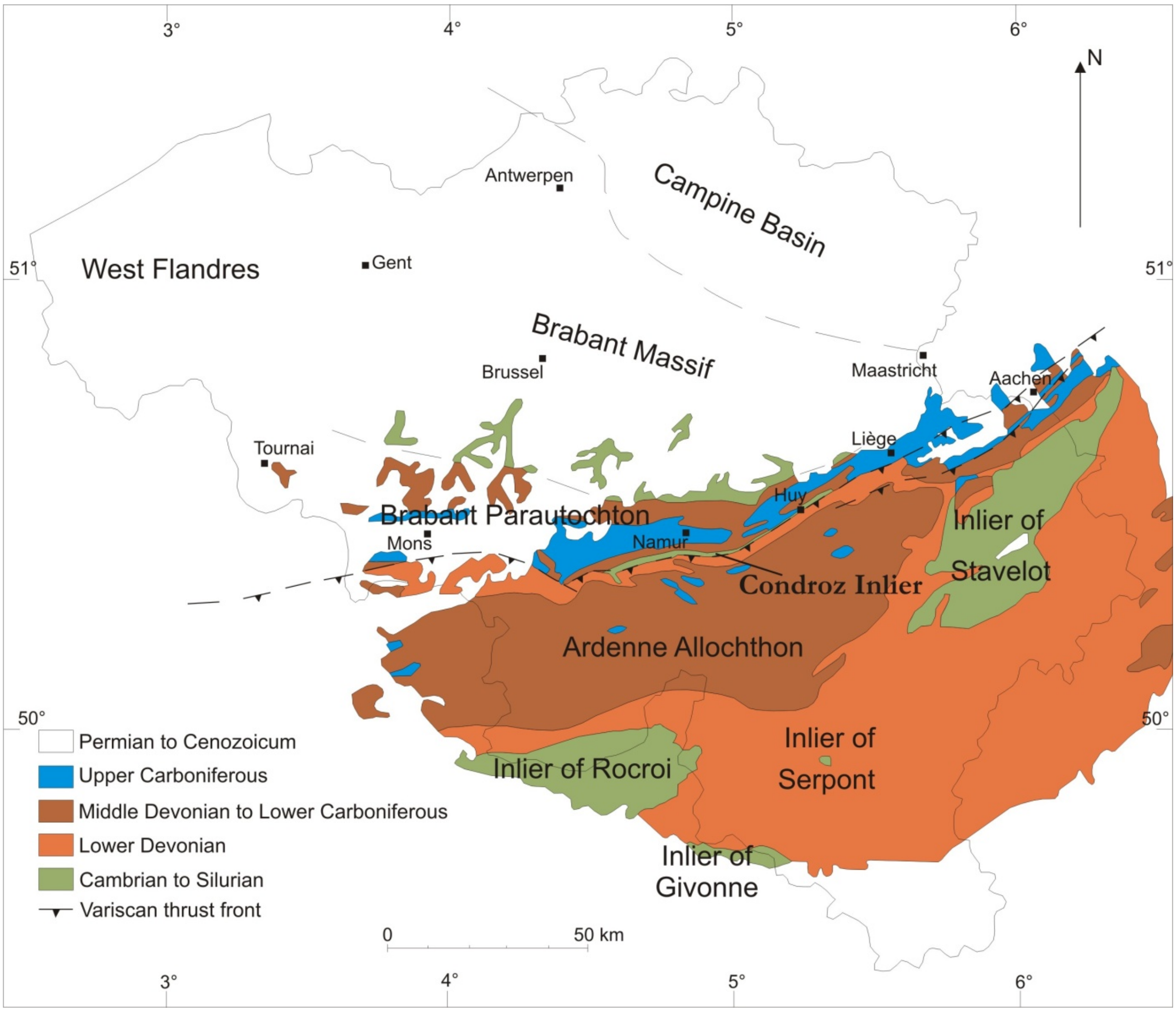


Fig. I.4.1. Simplified geological map of Belgium. The areas where the Lower Palaeozoic outcrops are indicated in green. Adapted from Fielitz & Mansy (1999).

The Condroz Inlier belongs to one of the six areas of Belgium where the Lower Palaeozoic outcrops besides the Brabant Massif, the Stavelot Inlier, the Rocroi Inlier, the Givonne Inlier and the Serpont Inlier (see fig. I.4.1). These last four are named the Ardennes Inliers. The Condroz Inlier is a narrow belt consisting of mainly siliciclastic rocks of the Ordovician and the Silurian situated south of the Sambre and Meuse rivers and north of the Condroz Plateau. It extends from Bouffioulx (east-southeast of Charleroi) to Engis (west-southwest of Liège) over a length of approximately 65 km and a width varying between approximately 0.5 en 4 km (see fig. I.4.2). It is bordered in the north by the Brabant Parautochthon and in the south

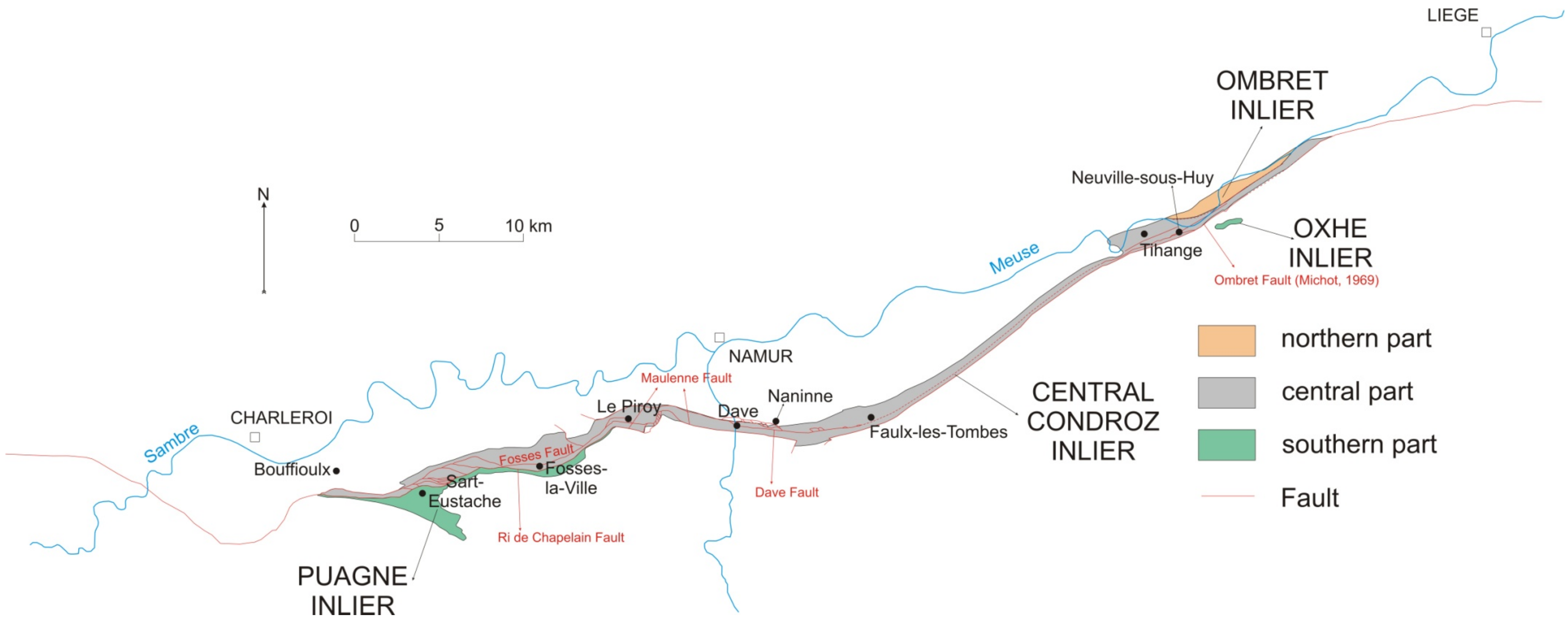


Fig. I.4.2. The four tectonic wedges composing the Condroz Inlier. The location of the studied sections, and other sections mentioned, is indicated. Adapted from Vanmeirhaeghe (2006b) and originally compiled from Michot (1932a, b, 1934, 1969), Vandevelde (1976), Maes *et al*. (1978).

by the Ardenne Allochthon. The Condroz Inlier has an west-southwest to east-northeast orientation west of the Meuse river and southwest to northeast orientation east of the Meuse river.

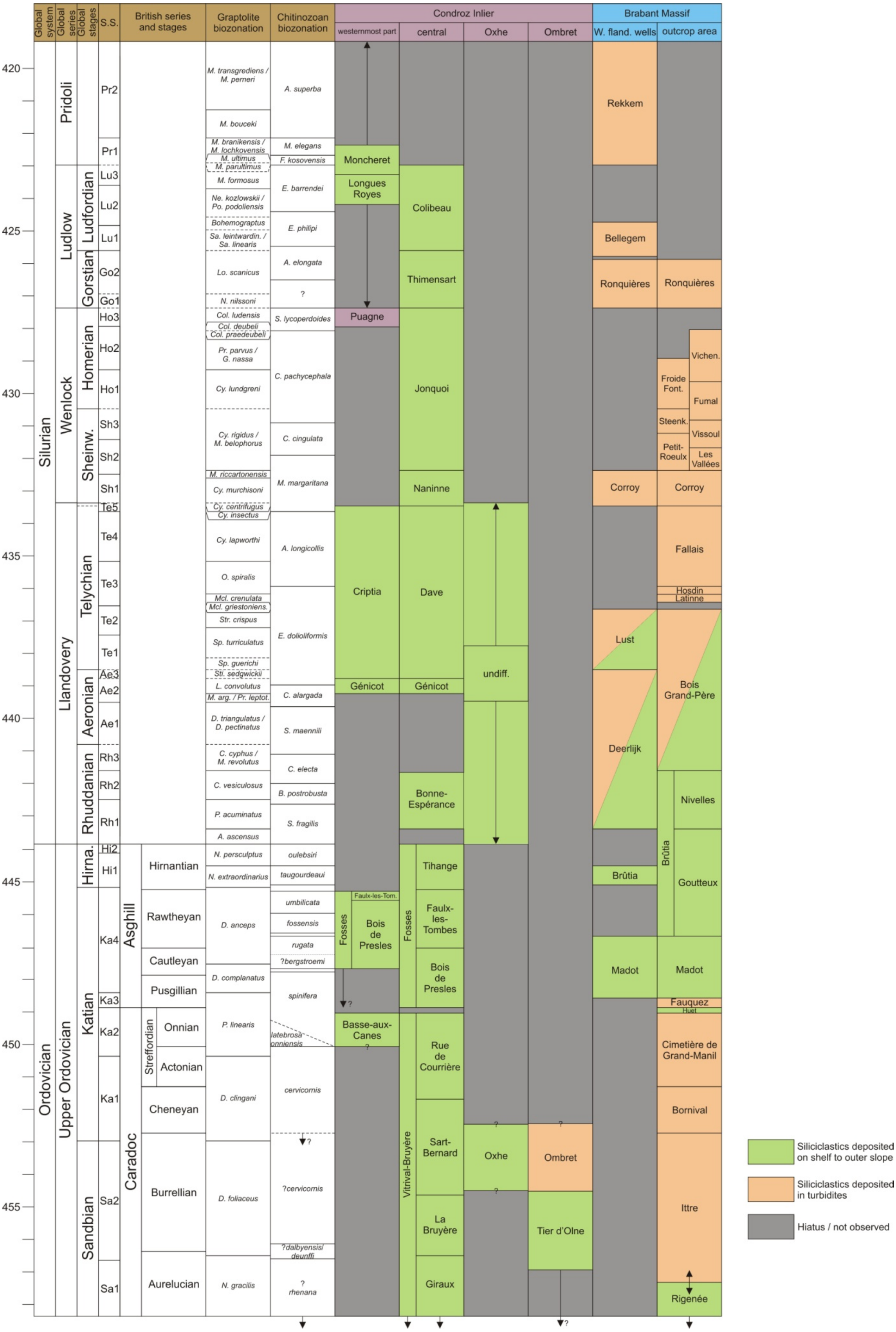
Four tectonic wedges can be distinguished within the Condroz Inlier (see fig. I.4.2; Michot, 1980; Verniers *et al.*, 2001), with their own characteristic sediments but they can share these with other zones:
1. a central and main part, the central Condroz Inlier, with no tectonic cleavage except proven at one place (Ruisseau des Chevreuils, Dave) by Debacker & Vanmeirhaeghe (2007);
2. two southern parts with the Puagne Inlier in the west and the Oxhe Inlier in the east both with a Variscan tectonic cleavage (Fourmarier, 1939; Michot, 1979);
3. a northern part, the Ombret Inlier situated in the northeast with a "Caledonian" tectonic cleavage (Valcke & Debacker, 2002).
These tectonic wedges were originally separated from each other, but Variscan tectonics have brought them together to their current position.

4.1.2. Deformation

The Condroz Inlier was deformed twice: by the Caledonian (s.l.) Orogeny (a.o. Fourmarier, 1931, 1939; Michot, 1928, 1932a, b, 1954, 1979) and by the Variscan Orogeny. The Caledonian (s.l.) Orogeny resulted in folding and cleavage formation in the Ombret Inlier (Valcke & Debacker, 2002) and in the Ruisseau des Chevreuils section, Dave in the central Condroz Inlier (Debacker & Vanmeirhaeghe, 2007). The absence of a Caledonian cleavage in the main part of the Condroz Inlier is attributed to insufficient sediment loading (Fourmarier, 1939; Michot, 1980; Debacker & Vanmeirhaeghe, 2007). The Condroz Inlier was affected by the Variscan orogeny during the Serpukhovian – Pennsylvanian interval. This resulted, according to Michot (1932a, 1954), in a further accentuating of the Caledonian folds. During later phases brittle tectonics caused northvergent thrusting. Only in the southern part of the Condroz Inlier, the Puagne Inlier and the Oxhe Inlier, a Variscan cleavage is developed (Michot, 1954, 1980). The Variscan orogeny pushed the Ardennes Allochton to the north, with the Variscan thrust front approximately coinciding with the location of the Condroz Inlier. The particular position of the Condroz Inlier together with its poor degree of exposure and almost absence of cleavage can explain why the structural architecture and the age of deformation is still under discussion (for an overview see Sintubin, 1992 and Valcke, 2001a).

4.1.3. Litho-, bio- and chronostratigraphy

Fig. I.4.3. Next page. Overview of the litho-, bio- and chronostratigraphy of the Condroz Inlier and the Brabant Massif before we started our study. This figure is based on Verniers *et al.* (2001), Vanmeirhaeghe (2006b) and Herbosch & Verniers (2014). The chronostratigraphy, numerical ages and graptolite biozonation are from Gradstein *et al.* (2012). The stage slices for the Upper Ordovician are from Bergström *et al.* (2009), these for the Silurian are from Cramer *et al.* (2011a), the chitinozoan biozonation of Avalonia for the Upper Ordovician is from Vandenbroucke (2008b), the Silurian global chitinozoan biozonation is from Verniers *et al.* (1995).


Global system
Global series
Global stages
S.S.
British series and stages
Graptolite biozonation
Chitinozoan biozonation
Condroz Inlier
westernmost part
central
Oxhe
Ombret
Brabant Massif
W. fland. wells
outcrop area
420
425
430
435
440
445
450
455
Silurian
Ordovician
Pridoli
Ludlow
Wenlock
Llandovery
Upper Ordovician
Ludfordian
Gorstian
Homerian
Sheinw.
Telychian
Aeronian
Rhuddanian
Hirna.
Katian
Sandbian
Pr2
Pr1
Lu3
Lu2
Lu1
Go2
Go1
Ho3
Ho2
Ho1
Sh3
Sh2
Sh1
Te5
Te4
Te3
Te2
Te1
Ae3
Ae2
Ae1
Rh3
Rh2
Rh1
Hi2
Hi1
Ka4
Ka3
Ka2
Ka1
Sa2
Sa1
Asghill
Caradoc
Streffordian
Hirnantian
Rawtheyan
Cautleyan
Pusgillian
Onnian
Actonian
Cheneyan
Burrellian
Aurelucian
M. transgrediens / M. perneri
M. bouceki
M. branikensis / M. lochkovensis
M. ultimus
M. parultimus
M. formosus
Ne. kozlowskii / Po. podoliensis
Bohemograptus
Sa. leintwardin. / Sa. linearis
Lo. scanicus
N. nilssoni
Col. ludensis
Col. deubeli
Col. praedeubeli
Pr. parvus / G. nassa
Cy. lundgreni
Cy. rigidus / M. belophorus
M. riccartonensis
Cy. murchisoni
Cy. centrifugus
Cy. insectus
Cy. lapworthi
O. spiralis
Mcl. crenulata
Mcl. griestoniens.
Str. crispus
Sp. turriculatus
Sp. guerichi
Sti. sedgwickii
L. convolutus
M. arg. / Pr. leptot.
D. triangulatus / D. pectinatus
C. cyphus / M. revolutus
C. vesiculosus
P. acuminatus
A. ascensus
N. persculptus
N. extraordinarius
D. anceps
D. complanatus
P. linearis
D. clingani
D. foliaceus
N. gracilis
A. superba
M. elegans
F. kosovensis
E. barrendei
E. philipi
A. elongata
?
S. lycoperdoides
C. pachycephala
C. cingulata
M. margaritana
A. longicollis
E. dolioliformis
C. alargada
S. maennili
C. electa
B. postrobusta
S. fragilis
oulebsiri
taugourdeaui
umbilicata
fossensis
rugata
?bergstroemi
spinifera
latebrosa
onniensis
cervicornis
?cervicornis
?dalbyensis/ deunffi
?
rhenana
Moncheret
Longues Royes
Puagne
Criptia
Génicot
Fosses
Bois de Presles
Faulx-les-Tom.
Basse-aux-Canes
Colibeau
Thimensart
Jonquoi
Naninne
Dave
Génicot
Bonne-Espérance
Tihange
Faulx-les-Tombes
Bois de Presles
Rue de Courrière
Sart-Bernard
La Bruyère
Giraux
Vitrival-Bruyère
undiff.
Oxhe
Ombret
Tier d'Olne
Rekkem
Bellegem
Ronquières
Corroy
Lust
Deerlijk
Brûtia
Madot
Ronquières
Vichen.
Froide Font.
Fumal
Steenk.
Vissoul
Petit-Roeulx
Les Vallées
Corroy
Fallais
Hosdin
Latinne
Bois Grand-Père
Nivelles
Brûtia
Goutteux
Madot
Fauquez
Huet
Cimetière de Grand-Manil
Bornival
Ittre
Rigenée
Siliciclastics deposited on shelf to outer slope
Siliciclastics deposited in turbidites
Hiatus / not observed

In the following chapter we give an overview of the litho-, bio- and chronostratigraphy of the Condroz Inlier of the Upper Ordovician to Silurian as it was known before we started our study (see also fig. I.4.3.). It will be mainly based on Verniers *et al.* (2001) and Vanmeirhaeghe (2006b).

4.3.1.1. The central Condroz Inlier

The Vitrival-Bruyère Formation comprises four members from bottom to top (Vanmeirhaeghe, 2006b): the Giraux Member, the La Bruyère Member, the Sart-Bernard Member and the Rue de Courrière Member. The descriptions below are according to Vanmeirhaeghe (2006b) unless indicated otherwise. The Giraux Member consists of micaceous siltstone and mudstone with only a few, thin (max. 30 cm), pyrite-bearing, fine-grained grey sandstone beds. The thickness is approximately 100 m. Graptolites found by Vanmeirhaeghe (2006b) of the *Nemagraptus gracilis* Biozone occur, although a correlation with the upper *Hustedograptus teretiusculus* Biozone or the *Climacograptus peltifer* Biozone cannot be excluded. Billiaert (2000) recognized the *Laufeldochitina stentor* Biozone. These fossils indicate an interval of the late Llandeilo (late Llanvirn, late Darriwilian) to Aurelucian (early Caradoc, early Sandbian) for the Giraux Member. The La Bruyère Member consists of micaceous siltstone and mudstone with probably five sandstone dominated intervals. These intervals, with a total thickness of approximately 1 m to 5 m, consist of thick sandstone beds, with a thickness up to more than 2 m, separated by mud- to siltstone beds a few cm or less thick. The thickness of the member is approximately 120 m. Graptolites from the middle part of the La Bruyère Member belong to the *Climacograptus peltifer* Biozone (Maillieux, 1926) corresponding to the upper Aurelucian to middle Burrelian (middle to upper Sandbian). Chitinozoans (Vanmeirhaeghe, 2006b) from the lower part of the member indicate a broad late Arenig (early Darriwilian) to middle Caradoc (early Katian) age, chitinozoans from the upper part indicate the middle to late Caradoc (early to middle Katian). The Sart-Bernard Member consists of grey to dark grey micaceous siltstone and mudstone with a rare sandstone bed of maximum 30 cm thick. The thickness is approximately 100-200 m. Owens & Servais (2007) place the Sart-Bernard Member in the upper Llanvirn (upper Darriwilian) to Cheneyan (middle to upper Caradoc, lower Katian) based on trilobite data, unpublished graptolite data of Maletz and preliminary chitinozoan data of Vanmeirhaeghe. Vanmeirhaeghe (2006b, 2007a) recognized in this member the *Spinachitina cervicornis* Biozone indicating the middle Burrelian to (early) Cheneyan. Before the study of Vanmeirhaeghe (2006b) this unit was categorized as a formation. But he prefered to include this unit within the Vitrival-Bruyère Formation. The Rue de Courrière Member consists of dark grey micaceous siltstone and mudstone with numerous thin sandstone beds (generally less than 25 cm thick) and some microconglomerate levels. The thickness of the member is approximately 60 m. The chitinozoans of the latter member belong to the *Spinachitina cervicornis* Biozone. Chitinozoans in the upper 12 m of the member can be correlated with the lower part of the *Fungochitina spinifera* Biozone. This indicates an age of the Cheneyan (middle Caradoc, early Katian) to late Onnian (late Caradoc, middle Katian).

The Fosses Formation comprises three members (Vanmeirhaeghe, 2006b) from bottom to top: the Bois de Presles Member, the Faulx-les-Tombes Member and the Tihange Member. The formation occurs in the central Condroz Inlier and in the Puagne Inlier but with different thicknesses while the Tihange Member is lacking in the Puagne Inlier. The Bois de Presles Member consists of burrowed, calcareous or decalcified green-brown to grey siltstone or fine sandstone with sometimes oblique lamination and occasionally thin limestone levels. Macrofossils occur and most of them are concentrated in layers, interpreted as tempestites (Vanmeirhaeghe & Verniers, 2004; Vanmeirhaeghe *et al.*, 2005; Vanmeirhaeghe, 2006a). Dark grey bioturbation traces occur in the layers not deposited as tempestites. At the base of the member calcareous or decalcified, fossiliferous siltstone occur with dispersed, dark nodules (possibly chert) occurring until approximately 2 m above the base. The burrows in the Bois de Presles Member become more abundant higher up making a gradual change to the covering Faulx-les-Tombes Member. The thickness in the Puagne Inlier is estimated between approximately 75 m and 95 m. In the central Condroz Inlier the thickness is estimated between approximately 23.8 m to 50 m. In the Puagne Inlier a ?Pusgillian but certainly Cautleyan to late Rawtheyan (middle to late Katian) age was found based on the chitinozoans: the *Tanuchitina bergstroemi* Biozone and the *Conochitina rugata* Biozone (Billiaert, 2000); Vanmeirhaeghe & Verniers (2004) observed additionally the *Bursachitina umbilicata* Biozone in the upper part of the member. In the central Condroz Inlier an age of Pusgillian to early Rawtheyan (middle to late Katian) has been found by the chitinozoans: possible presence of the *Fungochitina spinifera* Biozone and the *Tanuchitina bergstroemi* Biozone and proved presence of the *Conochitina rugata* Biozone (Vanmeirhaeghe, 2006a). The Faulx-les-Tombes Member consists of grey-green to grey, micaceous siltstones containing dark grey fusiform to elliptic bioturbation traces. This facies has been first described by Lassine (1913a) as “schistes mouchetés”. In the Puagne Inlier the thickness is 3 m to 5 m thick. In the central Condroz Inlier the thickness is >66 m to >85 m. In the Puagne Inlier the *Bursachitina umbilicata* Biozone is recognized indicating a late Rawtheyan age (late Katian; Vanmeirhaeghe & Verniers, 2004). In the central Condroz Inlier an early to late Rawtheyan (late Katian) age was deduced on the presence of the *Conochitina rugata* Biozone and the *Bursachitina umbilicata* Biozone (Vanmeirhaeghe, 2006a). It implies a facies difference and a diachronous boundary between the Puagne Inlier and the central Condroz Inlier for the Bois de Presles and the Faulx-les-Tombes Member (see chapter I.1.1.4). The lower part of the Tihange Member consists of grey siltstone with rusty patches along the stratification and some bioturbations. It is coarser than the underlying unit with progressively more rusty patches. Above this lower part coarse-grained, laminated siltstone and fine-grained sandstone occur with a few thin medium- to coarse-grained sandstone beds. The thickness of this member is approximately between 15 m and 21 m. The Tihange Member is tentatively placed by Vanmeirhaeghe (2006b) in the Hirnantian based on the underlying Faulx-les-Tombes Member and the covering Bonne Espérance Formation with at the base early Rhuddanian.

The Bonne-Espérance Formation consists of dark grey to dark green, laminated mudstone containing graptolites. Higher up the laminations seem to be less abundant. Some pale, clayey levels occur, probably having a volcanosedimentary origin. Graptolites of the *Parakidograptus acuminatus* Biozone and the *Cystograptus vesiculosus* Biozone occur (Malaise, 1907; Michot, 1932a, 1934, 1954) indicating an early to middle Rhuddanian age.

The Génicot Formation consists of grey, medium grey to dark grey, micaceous siltstone and mudstone with (laminated) sandstone beds and conglomeratic levels. A 3.5 m thick level of micaceous mudstone and siltstone occurs. In the lower part densely spaced, millimetric, sometimes patchy rusty laminae do occur. The thickness is approximately 100 meters. This formation occurs in the central Condroz Inlier and in the Puagne Inlier. Graptolites of the *Lituigraptus convolutus* Biozone occur (Michot, 1927, 1928, 1934; Zalasiewicz in Vanmeirhaeghe, 2006b) indicating the middle to upper Aeronian. Brachiopods indicate the Aeronian and confirm this attribution (Harper in Vanmeirhaeghe, 2006b).

The Dave Formation consists of bluish to blackish, slightly sandy shale at type locality in Dave (Michot, 1932b, 1934). At Neuville-sous-Huy (Maes *et al.*, 1978) the formation consists of greenish, greyish and red shale containing eight volcanosedimentary levels. Some coarser levels up to sandstone occur. The thickness is tentavily estimated at several hundred meters (Verniers *et al.*, 2001). At Dave graptolites of the *gregarius-convolutus-sedgwickii*, *sedgwickii-turriculatus* and *crenulata* Biozones have been found by Michot (1932b, 1934). At Neuville-sous-Huy graptolites belong to the *turriculatus-crispus-griestoniensis-crenulata* Biozone. A chitinozoan study by Verniers (unpublished) indicate the presence of the *dolioliformis* and *longicollis* global Biozones. These data give a Telychian age for the Dave Formation. The definition of the Dave Formation was emended and enlarged by Michot (1954) spanning the whole Llandovery including the later defined Bonne-Espérance and Génicot Formations. Vanmeirhaeghe (2006b) preferred to restrict the Dave Formation to its original sense of Michot (1932b) giving a late Aeronian to Telychian age.

The Naninne Formation consists of slightly calcareous, slightly sandy, laminated shale with some sandstone levels (Michot, 1954; Martin, 1969a). In the Neuville-sous-Huy area it consists of green to green-grey shale with intercalations of sandstone and red shale. Blue-grey, finely laminated shale occur also. In the Neuville-sous-Huy area three volcanosedimentary levels occur. The thickness is approximately 50 m according to Michot (1957) and more than 90 m according to Vandevelde (1976) and Maes *et al.* (1978). The *Cyrtograptus centrifugus*, *C. murchisoni* and the *Monograptus riccartonensis* Biozones were recognized (Lassine, 1913b, Michot, 1932b, Michot, 1934, Maes *et al.*, 1978) indicating an early Wenlock age. Chitinozoans of the *Margachitina margaritana* Biozone (Verniers, unpublished) confirms this attribution.

The Jonquoi Formation consists of green shale and sandy shale (Michot, 1954; Martin, 1969a), grey-brown, sandy, laminated shale and grey-blue and green, finely laminated shale with a level of calcareous nodules (Maes *et al.*, 1978). The thickness is approximately 300 m (Michot, 1957). Graptolites were described allowing an attribution to the *Cyrtograptus linnarssoni*, the *C. rigidus* Biozones up to the possibly *Cyrtograptus lundgreni* Biozone (Manil & Ubaghs, 1940; Michot, 1954; Maes *et al.*, 1978).

The Thimensart Formation consists of shale, laminated, sandy shale and thin levels of sandstone. The thickness is difficult to estimate but in the order of 100 m (Michot, 1957). Graptolites indicate the presence of the *Neodiversograptus nilssoni*, *Cucullograptus scanicus* and *Pristiograptus tumescens* Biozones, all pointing to the Gorstian.

The Colibeau Formation consists of dark grey to brownish black, coarse-grained shale containing a lot of mica with rare intercalations of clayey sandstone (Maillieux, 1930; Martin, 1969a). The thickness is 650 m (Michot, 1957). Three brachiopod species have been found: *Spirifer elevatus*, *Plethoryncha percostata* and *Stropheodonta simulans*. They indicate the upper Ludlow (Malaise, 1913; Maillieux, 1930).

4.3.1.2. The Puagne Inlier

The Basse-aux-Canes Formation consists of, according to Verniers *et al.* (2001), greenish grey or dark grey silty shale, often sandy siltstone, with irregular jointing. White mica is often present. The formation contains no (Verniers *et al.*, 2001) or hardly any substantial sandstone beds (Delcambre & Pingot, 2004). The thickness is estimated between 100 and 150 m. Vanmeirhaeghe (2006b) found chitinozoans indicating the presence of the *Fungochitina spinifera* Biozone and concluded a latest Caradoc to early Ashgill (middle Katian) age.

The Criptia Group consists of green, green-grey and dark green shale and silty shale, almost without any visibly stratification. A green to green-grey shale unit and an overlying darker coloured unit can be distinguished (Verniers *et al.*, 2001). The thickness is tentatively estimated at several hundred meters (Verniers *et al.*, 2001). (At least a part of) the unit has been tentatively correlated with the Dave Formation by Vanmeirhaeghe (2006b) and hence a (late) Llandovery age is assigned to this unit without any fossil evidence. Verniers *et al.* (2001) do not exclude a possible Wenlock to early Ludlow age. It should be younger than the underlying Génicot Formation.

4.3.1.3. The Ombret Inlier

The Tier d'Olne Formation consists of dark to medium grey slate, with sometimes obliquely laminated, micaceous coarse-grained siltstone to fine-grained sandstone beds (Vanmeirhaeghe, 2001a, b; Vanmeirhaeghe & Verniers, 2002). Several volcanosedimentary beds occur towards the top with a thickness less than 10 cm. The thickness is estimated at a minimum of 208 meters. Vanmeirhaeghe (2001a, b) and Vanmeirhaeghe & Verniers (2002) indicate a Llanvirn (middle to late Darriwilian) to Burrellian (middle Caradoc, late Sandbian to early Katian) age with an Aurelucian to Burrellian (early to middle Caradoc, early Sandbian to early Katian) age for the upper part of the formation. The presence of *Calpichitina lenticularis* in the upper part of the formation indicates a late Soudleyan age (middle-late Burrellian, middle Caradoc, late Sandbian).

The Ombret Formation consists of an alternation of sometimes convoluted, cross-laminated fine sandstone, laminated siltstone and mudstone. They are interpreted as turbidites (Martin *et al.*, 1970; Vanmeirhaeghe, 2001a, 2001b; Vanmeirhaeghe & Verniers, 2002). Several volcanosedimentary beds occur at the base. The thickness is estimated at approximately 300 m by Martin *et al.* (1970); more than 261 m by Vanmeirhaeghe (2001a); a minimum of 328 m by Vanmeirhaeghe (2001b) and Vanmeirhaeghe & Verniers (2002). The thickness can be larger as the top is hidden by an important thrust fault (Valcke, 2001a, b; Valcke & Debacker, 2002) with hence the top is unknown. Vanmeirhaeghe (2006b) reinterpreted the chitinozoan data of Vanmeirhaeghe (2001a, 2001b) and Vanmeirhaeghe & Verniers (2002). He assigns a late Soudleyan to Cheneyan age (late Sandbian to early Katian) for the unit.

4.3.1.4. The Oxhe Inlier

The Oxhe Formation consists of an alternation of dark grey, micaceous mudstone and siltstone with decimetric, parallel or cross-laminated, micaceous, fine-grained sandstone beds (Dean, 1991; De Geest, 1998). The sediments are interpreted as tempestite deposits (De Geest, 1998) Thickness estimates are in the range of 200 m (Dean, 1991) to up to 900 m (De Geest, 1998). The trilobites of the Oxhe Formation indicate a Longvillian age (late Burrellian, middle Caradoc, late Sandbian to earliest Katian; Dean, 1991). The chitinozoans indicate the Burrelian (De Geest, 1998) confirming the age deduced by trilobites.

A Silurian unnamed unit occurs in the western extremity of the Oxhe Inlier (Michot, 1969; De Geest, 1998). It contains mudstone and micaceous, laminated siltstone alternated with thin beds of micaceous, fine sandstone. The acritarchs (Martin in Dean, 1991) indicate a Llandovery age with the exclusion of the Rhuddanian.

4.1.4. The Condroz Inlier from the late Onnian (middle Katian) to the middle Aeronian

Vanmeirhaeghe (2006b) compared the sediments of the Puagne Inlier (western part Condroz Inlier) with these of the central part of the central Condroz Inlier (e.g. in Faulx-les-Tombes) but also further to the east in Tihange (eastern part, central Condroz Inlier; see fig. I.4.4.). He proposed a model that compares the western Condroz Inlier with the eastern Condroz Inlier in time starting from the late Onnian (middle Katian) to the middle Aeronian. He observed a deeper facies in the western Condroz Inlier in comparison with a shallower facies in the eastern Condroz Inlier. Towards younger times an inversion takes place with shallower facies in the western Condroz Inlier in comparison with the eastern Condroz Inlier where a deeper facies is deposited. This inversion is explained by a tectonic uplift in the western Condroz Inlier with two possible causes for the tectonic uplift: the Ardennian Deformation Phase or the emplacement of a large pluton nearby. The model of Vanmeirhaeghe (2006b) expected a continuous sedimentation in Tihange during the Hirnantian, with an important sea-level drop occurring in that time slice, in contrast with the shallower Puagne Inlier where a hiatus is present in the sedimentation from the Hirnantian up to the early Aeronian. This model also explains the facies differences and diachronous boundary between the Puagne Inlier and the central Condroz Inlier for the Bois de Presles and the Faulx-les-Tombes Member in the Fosses Formation. The Faulx-les-Tombes Member is deposited in deeper environments in comparison with the Bois de Presles Member.

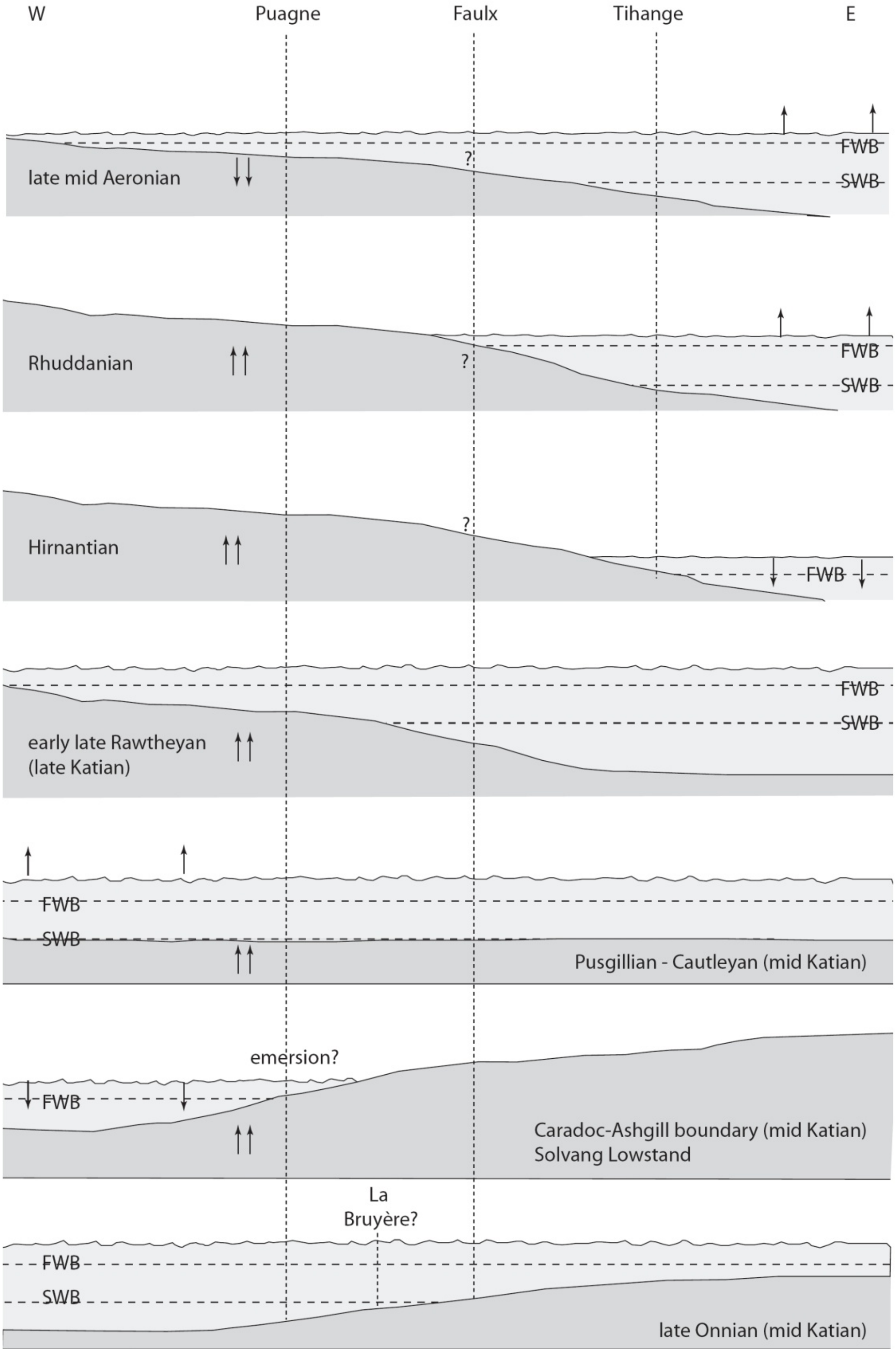


Fig. I.4.4. Proposed model of Vanmeirhaeghe (2006b) comparing the western Condroz Inlier with the eastern Condroz Inlier. The model shows an inversion from deeper facies in the western Condroz Inlier than in the eastern Condroz Inlier, to shallower facies in the western Condroz Inlier during the late Onnian (middle Katian) to middle Aeronian. From Vanmeirhaeghe (2006b).

4.2. Brabant Massif

4.2.1. Introduction

The Brabant Massif is a largely concealed, WNW-ESE directed deformation belt (see fig. I.4.5) developed during the Early Palaeozoic, occurring in the sub-surface of central and northern Belgium (Fourmarier, 1920; Legrand, 1968; De Vos *et al.*, 1993; Piessens *et al.*, 2006). Its sedimentary record is continuous from the upper half of the lower Cambrian, the upper half of Stage 2 of the Cambrian, to the top of the Silurian and even the lowermost Devonian (except an important hiatus in the Lower Ordovician) and is more than 13 km thick (Herbosch & Verniers, 2013 & 2014) containing mainly fine-grained siliciclastics. At first sight the Brabant Massif appears as a gently east-southeast plunging anticlinal structure with Cambrian sediments in the center flanked by Ordovician to Silurian strata. To the south, southwest and southeast it is unconformably overlain by Upper Palaeozoic deposits of the Brabant Parautochton (Mansy *et al.*, 1999); in the north it is unconformably overlain by Upper Palaeozoic deposits of the Campine Basin (see fig. I.4.1). To the northwest the Brabant Massif continues underneath the North Sea and links up with the East-Anglia Basin (Lee *et al.*, 1993). Both areas form part of the Anglo-Brabant Deformation Belt (Pharaoh *et al.*, 1993a, 1995; Van Grootel *et al.*, 1997) belonging to the continent Avalonia. In the United Kingdom southwest of the Anglo-Brabant Deformation Belt a Neoproterozoic cratonic block, the Midlands Microcraton, is proven to be present.

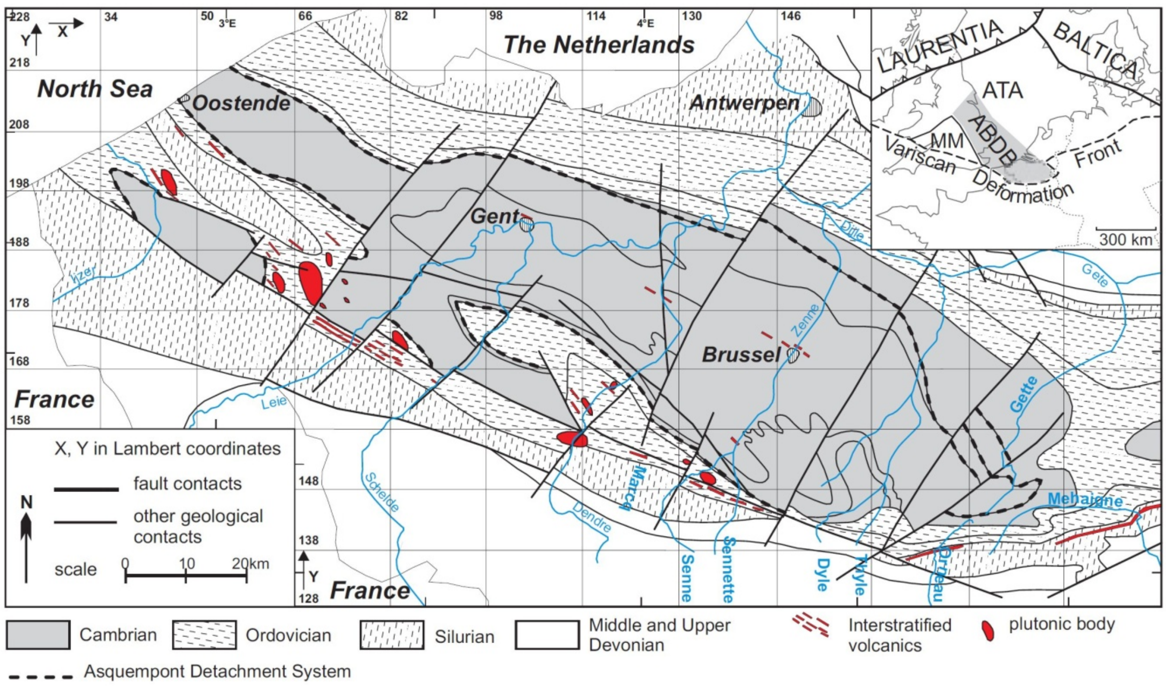


Fig. I.4.5. Geological subcrop map of the Brabant Massif. From Debacker, 2012 and after De Vos *et al.* (1993) and Van Grootel *et al.* (1997) The smaller picture at the upper right shows the position of the Anglo-Brabant Deformation Belt (ABDB) within Avalonia (ATA) flanking the Midlands Microcraton (MM).

The Brabant Massif is poorly exposed (only approximately 1 % of its total surface) and almost completely covered by Mesozoic and Cenozoic deposits (Fourmarier, 1920; Legrand, 1968). Only at its southern rim outcrops are present: in the valleys of the tributaries of the Scheldt (Dender, Senne, Dyle, Gete) and the Meuse (Orneau, Mehaigne, Ruisseau des Awirs) rivers. A substantial part of the knowledge of the Brabant Massif is based on boreholes (Legrand, 1968; Herbosch *et al.*, 1991, 2008) and the interpretation of gravimetric and aeromagnetic survey (BGS, 1994; Mansy *et al.*, 1999; Sintubin, 1999; Sintubin & Everaerts, 2002; Everaerts & De Vos, 2012).

The rocks of the Brabant Massif show low-grade metamorphism ranging from the epizone in the core to anchizone and diagenesis in the rim (Van Grootel *et al.*, 1997). The metamorphism is mainly caused by burial (pre-kinematic) with an additional syn-kinematic origin, needed in order to explain the higher metamorphic degree observed in parts of the Silurian rim (Debacker *et al.*, 2005).

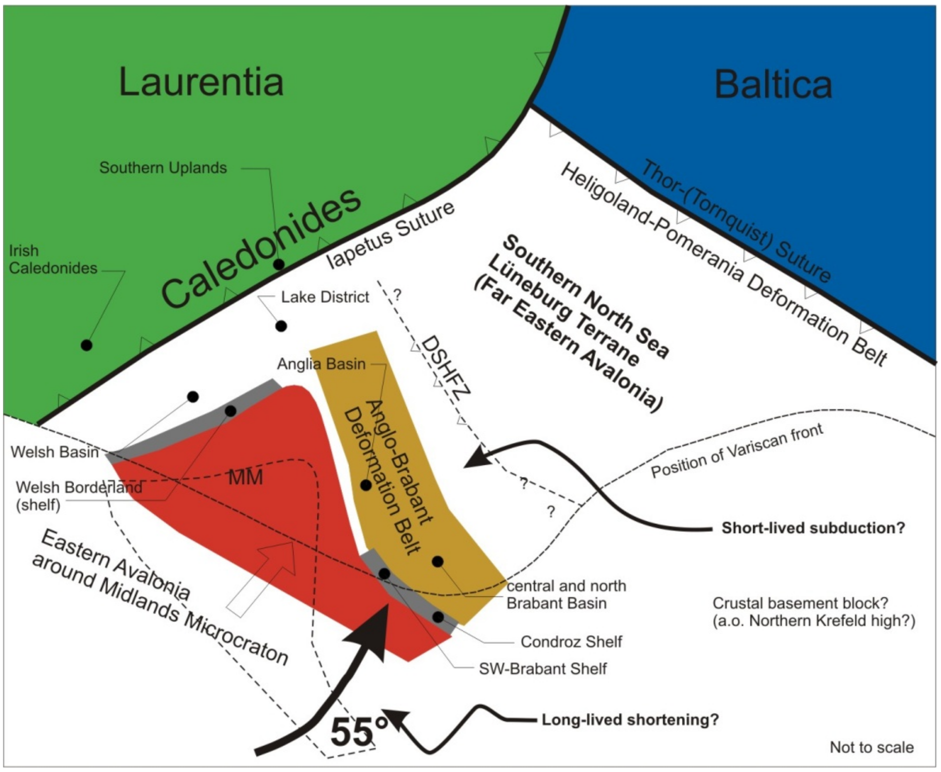


Fig. I.4.6. Schematic map showing the terrane assemblage of the eastern part of Avalonia. It shows the origin of the Anglo-Brabant Deformation Belt caused by an anticlockwise rotation of Wales and the Midlands Microcraton and also causing the short-lived subduction. MM: Midlands Microcraton; DSHFZ: Dowsing-South Hewett Fault Zone. Adapted from Verniers *et al.*, 2002a and originally from Debacker, 2001.

Along the southern part of the Brabant Massif, Upper Ordovician to lower Silurian magmatic rocks are present with a peak of the volcanic activity in the early Ashgill (middle to upper Katian; De la Vallée-Poussin & Renard, 1876; Corin, 1965; Verniers & Van Grootel, 1991;

Van Grootel *et al.*, 1997; Linnemann *et al.*, 2012). The age of this magmatism decreases towards the east. The magmatism is calc-alkaline, and explained by subduction of oceanic lithosphere beneath the Avalonia microcontinent (André *et al.*, 1986; Pharaoh *et al.*, 1993b; Van Grootel *et al.*, 1997; Verniers *et al.*, 2002a). According to Verniers *et al.* (2002a) subduction took place of a small oceanic floor within the Avalonian Terrane Assemblage between the microcontinent containing the Midlands Microcraton and the future Anglo-Brabant Deformation Belt, and the microcontinent Far Eastern Avalonia (see fig. I.4.6.). An alternative model is proposed by Linnemann *et al.* (2012). The core of the Brabant Massif is located above the boundary between the Midlands and Lüneburg-North Sea microcratons (see fig. I.4.7) within the Avalonia continent. The Avalonia-Baltica docking induced, in the southern part of eastern Avalonia, a reactivation of this lithospheric discontinuity. This reactivation generated partial melting of the lithosphere caused by movements of extension or transtension along a proto-Nieuwpoort-Asquempont Fault Zone. The partial melting give rise to the magmatism between the Upper Ordovician and the lower Silurian, between 460 and 430 Ma. The magmatism ceased caused by the Brabant core inversion and is a far-field effect of the collision between Baltica and Laurentia. The collision also caused a relative rotation between the Midlands Microcraton and the Lüneburg-North Sea Microcraton.

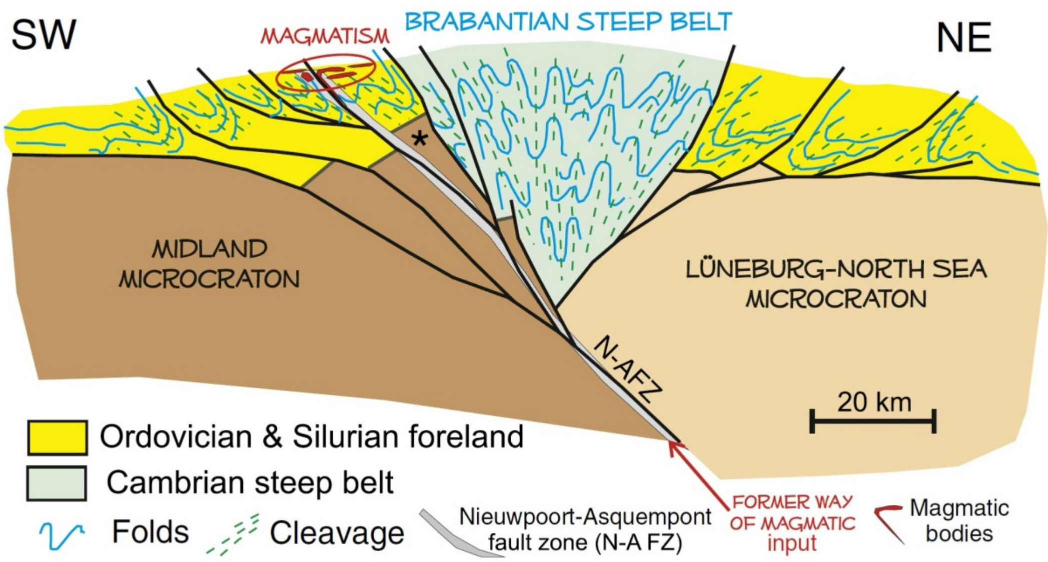


Fig. I.4.7. Schematic SW-NE cross-section of the Brabantian belt along the Dendre River. From Linnemann *et al.* (2012) and originally modified from Sintubin & Everaerts (2002) and Sintubin *et al.* (2009).

An important negative gravimetric anomaly underlies the magmatic arc (Everaerts *et al.*, 1996; Mansy *et al.*, 1999) which was interpreted as possibly a granitic batholith (De Vos, 1997). However Sintubin & Everaerts (2002) questioned the existence of the granitic batholith and interprets the negative gravimetric anomaly as an elevated cratonic basement block of granitic composition.

4.2.2. The sedimentary record in the Brabant Massif during the Upper Ordovician to Silurian

The sediments of the Upper Ordovician to lowermost Silurian of the Brabant Massif belong to the middle and upper part of the Rebecq Group (Herbosch *et al.*, 2014). They comprise from base to top the following formations: Rigenée, Ittre, Bornival, Cimetière de Grand-Manil, Huet and Fauquez formations belonging to megasequence 2 and Madot and Brûtia formations belonging to megasequence 3. They comprise terrigenous sediments: sandstone and mudstone with a grey, dark grey to black colour sometimes more greenish. Shelly fauna is present in the Huet and the Madot Formations; volcaniclastic rocks are present at the base of the Ittre Formation, in the Madot Formation and the upper part of the Brûtia Formation (Nivelles Member). The Rigenée formation is still deposited on the shelf. But the subsidence rate progressively increased from the Ittre to the Fauquez Formations, with the initiation of deeper marine turbiditic and pelagic sedimentation. Starting from the Madot Formation the depositional environment changed from a slope environment to a shelf.

The sediments of the lower Silurian to the lowermost Devonian of the Brabant Massif belong to the Orneau Group (Herbosch *et al.*, 2014). These formations contain terrigenous sediments of sandstone to mudstone. These sediments are grey to dark grey, black and sometimes more greenish. Starting from the middle Llandovery two areas develop where sediments are deposited (Verniers *et al.*, 2002a): in the southwestern Brabant Massif (south of the Ronse-Veurne line) a deep shelf environment develops where deposition took place; in the outcrop area, the central and north of the Brabant Massif deposition took place on a slope with turbidites and hemipelagites. These turbidites were distal at first and become more proximal higher up.

4.3. Evolution of the basin of the Condroz Inlier and the Brabant Massif

Verniers *et al.* (2002a) integrates multidisciplinary data sets from eastern Avalonia, east of the Midlands Microcraton, into a model for the Cambrian to middle Devonian basin development and deformation history of this area. The three megasequences described in Wales and the Welsh Borderland by Woodcock (1990) are also distinguished east of the Midlands Microcraton. These three megasequences correspond to three different geodynamic contexts. Megasequence 1, lower Cambrian to lower Tremadocian, corresponds to Avalonia that is attached to the northern edge of Gondwana. The high rate of sedimentation and the sedimentological observations in the Brabant Massif point to a rift environment (Verniers *et al.*, 2002; Sintubin & Everaerts, 2002; Debacker *et al.*, 2005; Linnemann *et al.*, 2012; Herbosch & Verniers, 2013). The separation of the Avalonia microcontinent away from Gondwana, and hence the division between megasequence 1 and megasequence 2, causes a stratigraphic hiatus in the Brabant Massif extending from the upper Tremadocian to the Floian and in the Condroz Inlier from the upper Tremadocian to the lower Darriwilian (Herbosch & Verniers, 2014). During megasequence 2 Avalonia was a separate continent and moves towards Baltica in northern direction. Shelf deposition took place with moderately thin sequences (Verniers *et al.*, 2002). The sedimentation is continuous in the Brabant Massif from megasequence 2 to 3 (Herbosch & Verniers, 2014), but in the Condroz Inlier a stratigraphic hiatus is present at the Caradoc-Ashgill boundary (middle Katian; Vanmeirhaeghe, 2006b).

Megasequence 3 starts with the soft docking of Avalonia-Baltica and corresponds to the continent Baltica-Avalonia and from the middle Silurian on to the continents Baltica-Avalonia-Laurentia. A shelf or foreland basin develops resulting in thick sedimentary beds in a.o. the Brabant Massif (Verniers *et al.*, 2002).

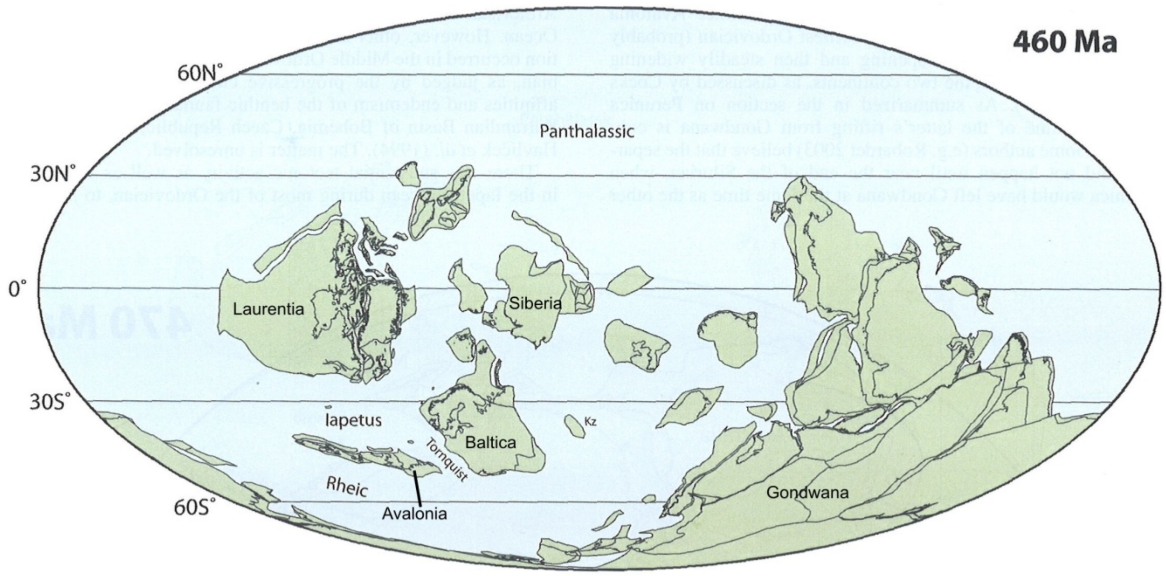
The depositional setting of megasequence 2 is the shelf in the Condroz Inlier. In the Brabant Massif a shelf environment exists from the lower Dapingian to the lowest Sandbian. Starting from the lower Sandbian to the middle Katian a slope environment exists in the Brabant Massif.

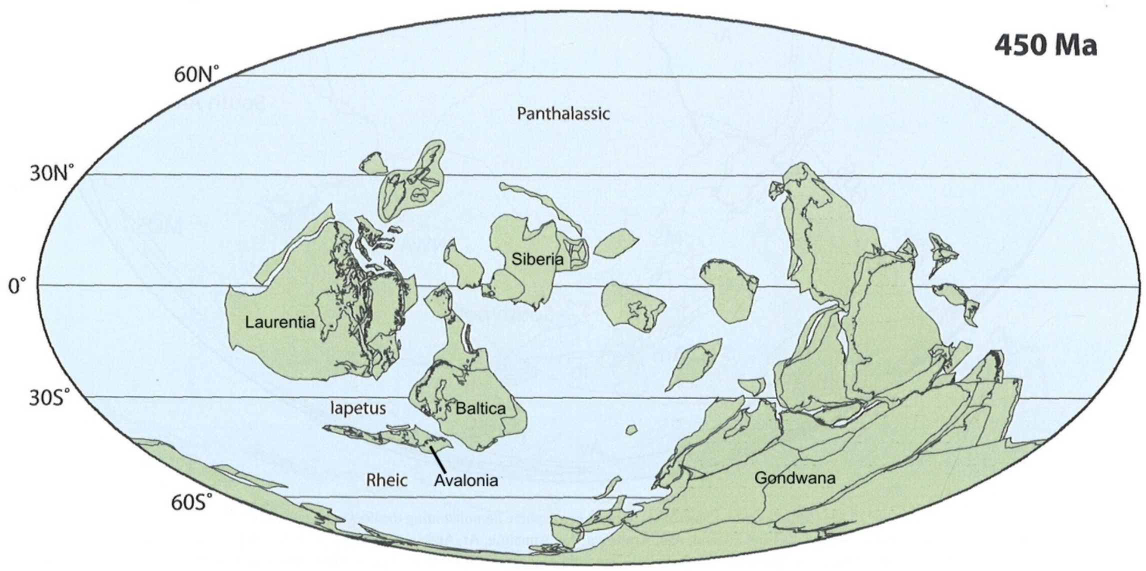
Megasequence 3 starts in the Brabant Massif and the Condroz Inlier with deposition on the shelf. Starting from the middle Llandovery (Verniers *et al.*, 2002) two distinct basinal areas develop in the Brabant Massif. A deep shelf environment persisted in the southwestern Brabant Massif (south of the Ronse-Veurne line) and the Condroz Inlier, while in the outcrop area, central and northern part of the Brabant Massif thick turbidites are deposited on the slope in a foreland basin. This foreland basin persisted into the Pridoli to lower Devonian (Verniers *et al.*, 2002; Debacker *et al.*, 2005). The interpretation of a foreland basin comes from the increase of the sediment thickness through megasequence 3 in the Brabant Massif (Van Grootel *et al.*, 1997; Debacker, 2001; Verniers *et al.*, 2002).

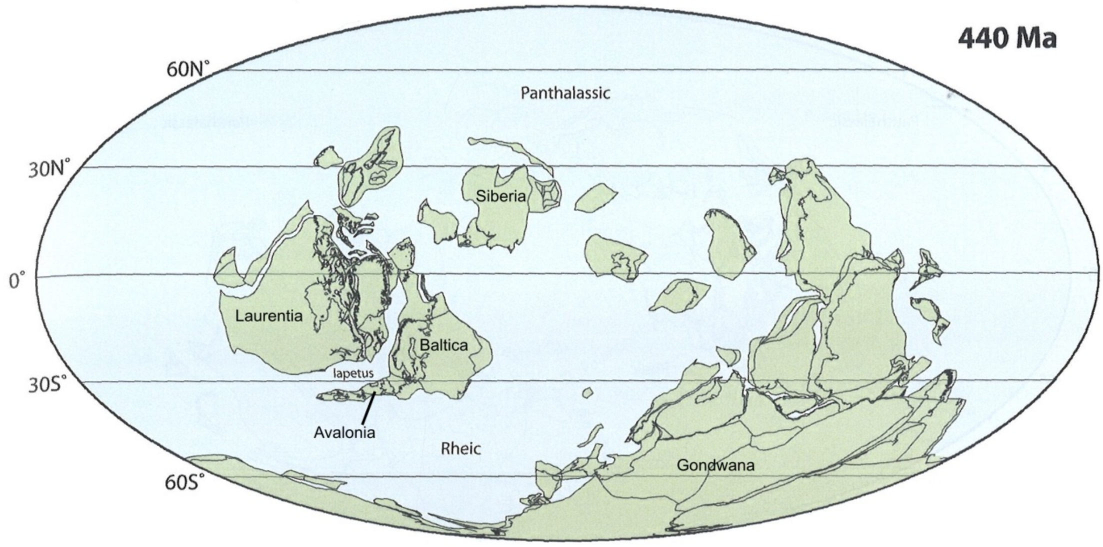
5. The world of the Upper Ordovician and Silurian

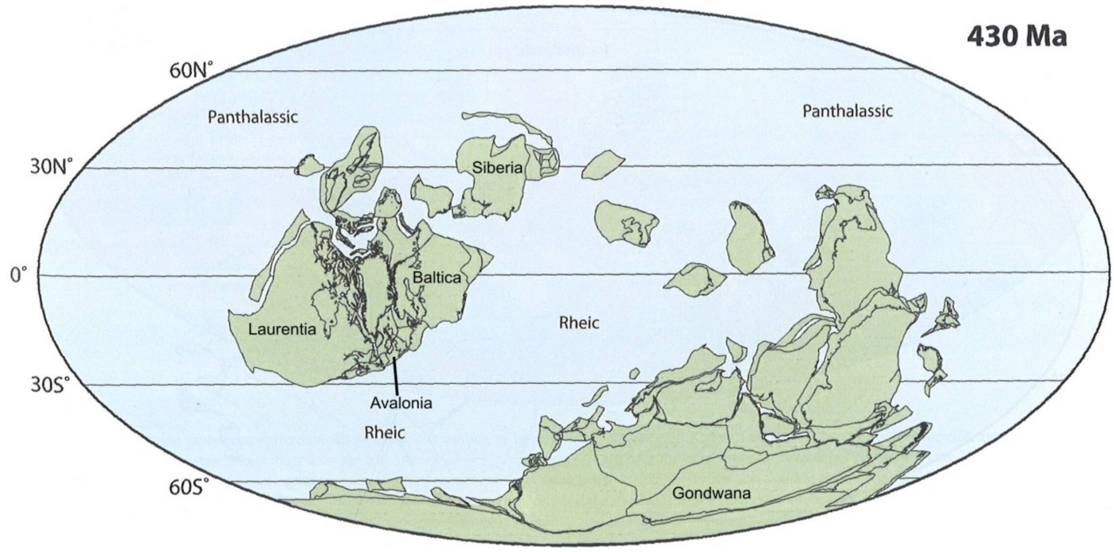
5.1. Palaeogeography

The best way to reconstruct the palaeogeography is by analyzing the magnetic anomaly stripes and fracture zones on the ocean floors. However the oceanic crust "in situ" is nowhere older than the Jurassic. Another method involves the use of hotspot traces on a plate that moves over a plume site which causes the hotspot. However the oldest hotspot is situated in the Lower Cretaceous. Hence for palaeogeographical reconstructions older than the Jurassic other methods are used. An important method is the use of palaeomagnetism. The palaeolatitude can be distinguished using this tool. Besides palaeomagnetism faunal and floral studies help to reconstruct the palaeogeography. Faunal and floral groups are created by differences in temperature and hence broadly to palaeolatitude but also physical barriers exist to which biota cannot cross. Certain sediments can also provide us more information about the position of the continents. Glacial deposits are a good example for this.






440 Ma
60N°
30N°
0°
30S°
60S°
Panthalassic
Siberia
Laurentia
Baltica
Iapetus
Avalonia
Rheic
Gondwana


430 Ma
60N°
30N°
0°
30S°
60S°
Panthalassic
Panthalassic
Siberia
Baltica
Laurentia
Rheic
Avalonia
Rheic
Gondwana

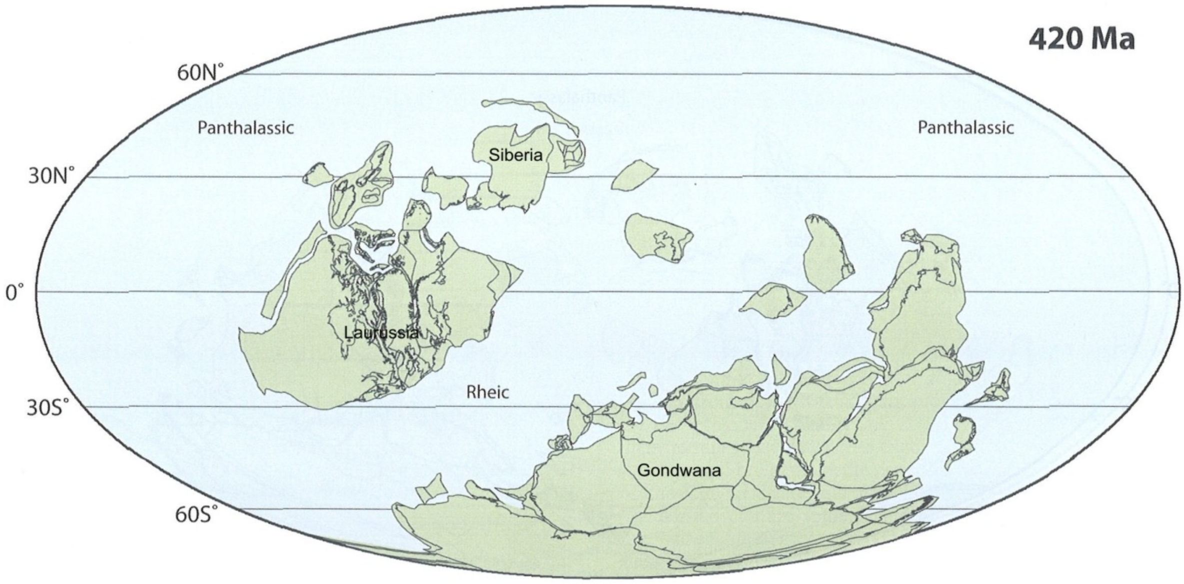

420 Ma
60N°
30N°
0°
30S°
60S°
Panthalassic
Panthalassic
Siberia
Laurussia
Rheic
Gondwana

Fig. I.5.1. Previous page. Palaeogeographical reconstructions according to Torsvik & Cocks (2013). The four major terranes are indicated besides the microcontinent Avalonia. From top to bottom: Sandbian-Katian-Rhuddanian-Telychian-Ludfordian.

During the Ordovician and the Silurian the northern hemisphere was covered by a very large ocean the Panthalassic Ocean (see fig. I.5.1). This ocean covered almost the whole northern hemisphere and most of the continents were situated on the southern hemisphere. Four major palaeocontinents were present: Gondwana, Laurentia, Baltica and Siberia (for a recent overview see Torsvik & Cocks, 2013).

Gondwana formed the largest continent during the Lower Palaeozoic. The core of Gondwana consisted of South America, Africa, Madagascar, Arabia, India, Antarctica and Australasia (Australia and New Guinea). At the start of the Palaeozoic other units were also present at the margins of Gondwana but these units left Gondwana at various times in the Palaeozoic causing the opening of the Rheic Ocean, Palaeotethys and others. These were the following smaller units, terranes or palaeocontinents: Armorican Terrane Assemblage, Avalonia, Sibumasu and possibly South China.

Laurentia is formed by the majority of present day Canada and the USA, Greenland, Svalbard, Scotland and northwestern Ireland. It was an independent continent from the Late Neoproterozoic until it merged with Avalonia-Baltica in the Silurian.

The eastern margin of Baltica coincides with the Urals. The southern margin is formed by the northern part of the Black Sea up to the eastern part of the North Sea and is largely delineated by the Trans-European Suture Zone. However some parts of Baltica lie south of this zone, such as the Holy Cross Mountains in Poland. The western margin is formed by the eastern part of the North Sea and the northern part by the Arctic Ocean. Between the Middle Cambrian and the Middle Ordovician Baltica underwent a significant anticlockwise rotation of 120°. Around the Ordovician-Silurian Avalonia docked with Baltica and these two continents collided with Laurentia in the middle Silurian. The continent that is formed is called Laurussia.

The continent Siberia did not include all of modern political Siberia but also adjacent areas of Mongolia, eastern Kazakhstan and northwestern China.

The sediments of the Condroz Inlier and the Brabant Massif are deposited on the microcontinent of Avalonia. We will discuss the history of the continent below. Avalonia stretched from Cape Cod, Massachusetts, through the Maritime Provinces and Newfoundland in Canada, southern Ireland, southern Britain, Belgium, the Netherlands and northwestern Germany and possibly the northwestern part of Poland. It stretches eastwards to the Trans-European Suture Zone. Avalonia is underlain by an early Neoproterozoic basement made up of a number of originally separate terranes. The term East and West Avalonia should be abandoned and during the Lower Palaeozoic one single Avalonia terrane exists (Cocks &

Fortey, 2009). Verniers *et al.* (2002a) introduced the term "Far Eastern Avalonia" as the part north of the Dowsing-South Hewett Fault Zone (see fig. I.4.6), comprising a.o. Rügen and Pomerania, with a narrow part of oceanic crust in between.

During the Cambrian to the lower Ordovician Avalonia was part of the continent Gondwana. Avalonia rifted away from Gondwana at the end of the Tremadocian (Cocks & Fortey, 2009). The Rheic Ocean opened between Avalonia and Gondwana. Avalonia was a separate unit through the rest of the Ordovician and docked with Baltica at the end of the Ordovician (Cocks & Torsvik, 2002; Torsvik & Rehnström, 2003; Cocks & Fortey, 2009) closing the Tornquist Ocean between the two. As already described above these two continents collide with Laurentia in the middle Silurian closing the Iapetus Ocean resulting in the Caledonide Orogeny.

Palaeomagnetic data has revealed an anticlockwise rotation of 55° of the Midlands Microcraton with respect to the Lake District (see fig. I.4.6) from the Caradoc (Sandbian-middle Katian) to the Emsian (Piper, 1997). This rotation is responsible for the Brabantian orogeny by the convergence of the Midlands Microcraton and the Lüneberg-North Sea Microcraton (Verniers *et al.*, 2002; Sintubin *et al.*, 2009). This convergence causes the long-lived shortening of the Brabant Massif with as final result the Anglo-Brabant Deformation Belt. The Cambrian sediments were already deforming in the late Llandovery causing the development of a foreland basin. The deformation front gradually spreads outwards deforming the sediments south and north of the Cambrian core (Debacker, 2001).

6. Chitinozoans

6.1. Introduction

Chitinozoans are a group of organic-walled microfossils. They appear in the Tremadocian and disappear at the end of the Famennian although Shen *et al.* (2013) suggests the presence already in Cambrian Stage 5 (see also below). Numerous hypotheses are formulated about their biological origin. But nowadays the consensus is that chitinozoans are the egg cases of small (a few millimeters to a few centimeters in length), entirely soft-bodied marine metazoans (Paris & Nõlvak, 1999). The chitinozoan animals, called chitinozoophorans (Grahn, 1981), is until now not found as a fossil and hence interpreted as soft-bodied. No other fossil group is known with a similar stratigraphic range and ecological position as these of the chitinozoans. They are ranged under an Incertae Sedis Group and the taxonomy is entirely based on morphological characteristics (Paris *et al.*, 1999).

6.1. Morphology

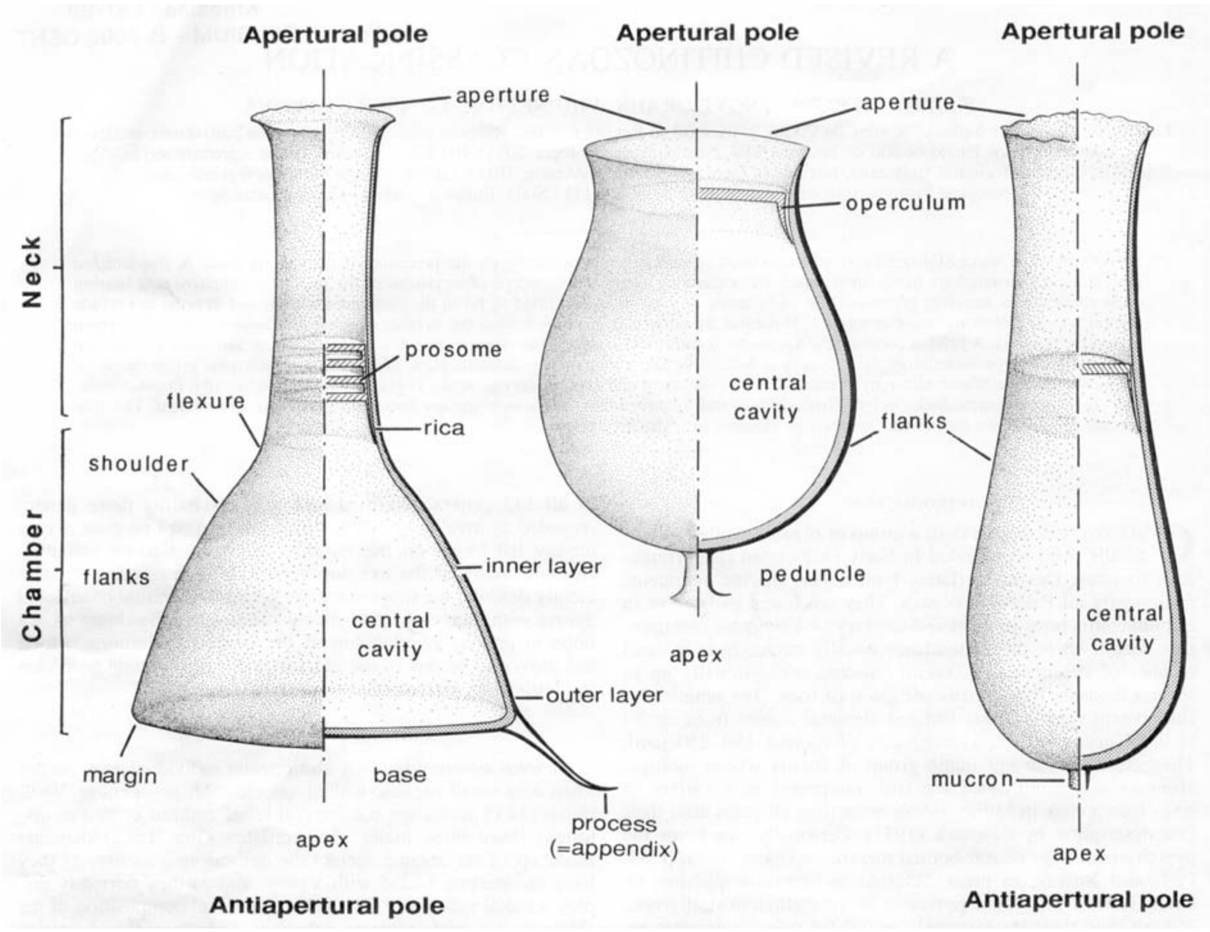


Fig. I.6.1. The main morphological features of the three types of chitinozoans. From Paris *et al*, 1999.

Chitinozoans have a radial symmetry with a purse-, vase-, or flask-like shape. They consist of a organic membrane, a tegument, forming a central cavity (see fig. I.6.1). The chitinozoan vesicle has a neck (although the neck is not present in the Family of the Desmochitinidae) passing into the flanks of the chamber via a flexure (concave) and/or shoulders (convex). At the end of the neck an opening is present, called the aperture. This opening can be sealed by a plug consisting of two types: an operculum (single disk) in the Family Desmochitinidae or a prosome (a cylinder consisting of multiple, horizontal septae) in the Family Conochitinidae and Family Lagenochitinidae. The rica is the antiapertureward membranous continuation below the operculum or prosome. The bottom of the chitinozoan vesicle is called the base and the center of the base is the apex. The side of the aperture is called the apertural pole; the side of the base is called the antiapertural pole. The form of the chamber can be lenticular, spherical, hemispherical, ovoid, conical, claviform or cylindrical (see fig. I.6.5a). The length of the chitinozoan vesicle varies mostly between 50 and 500 μm, and exceptionally can reach up to 2000 μm.

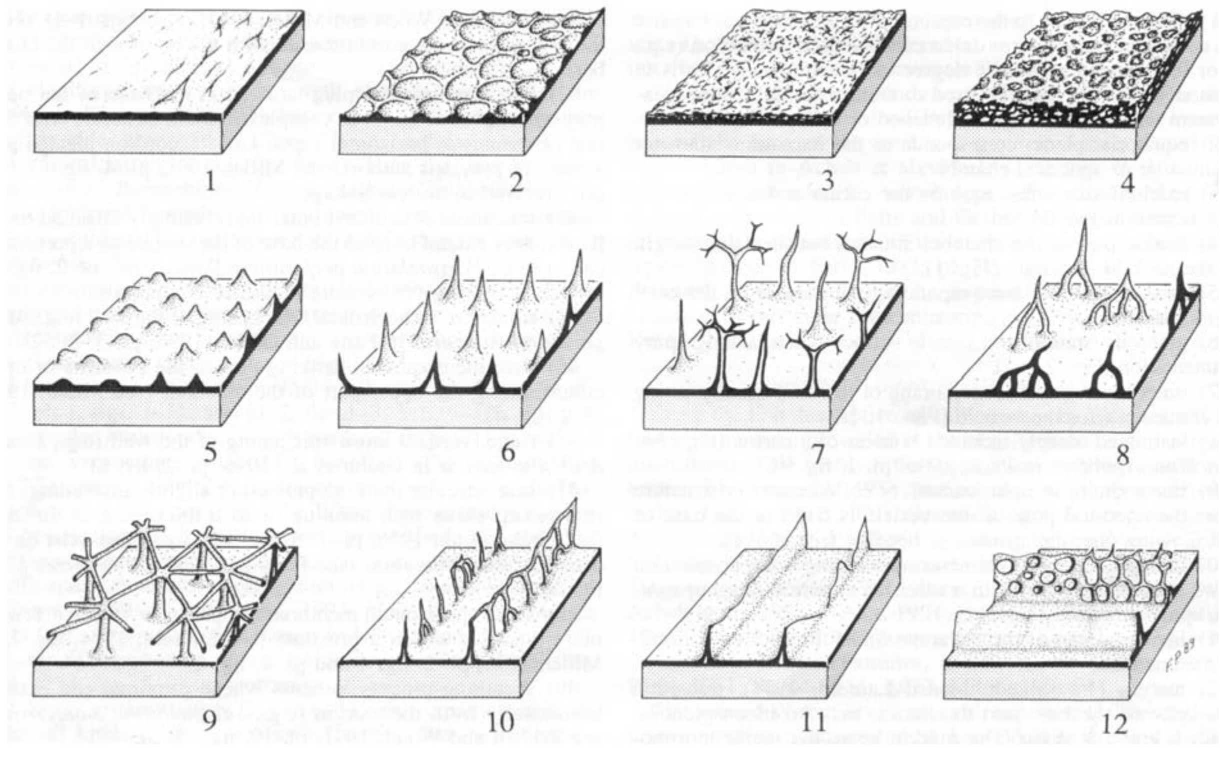


Fig. I.6.2. Different kinds of ornamentation of the chitinozoan vesicle wall. 1. Smooth, scabrate, vermiculate; 2. foveolate; 3. feltlike; 4. spongy; 5. verrucate (granules, tubercules and/or cones less than 2 μm high); 6. simple spines; 7. simple and branched hairs or spines; 8. bi and multirooted spines; 9. meshlike structure; 10. crests with vertical row of free or connected; 11. crests of weblike to discontinuous membranes; 12. complete or perforated/reticulated carina. Stippled = inner layer; black = outer layer. From Paris *et al*, 1999.

The organic wall, consisting of an inner and outer layer, can wear ornamentation on the outer layer in different ways (see fig I.6.2). It can be present on the entire wall or only a part of it, distributed randomly or in a geometric pattern. It can be present on certain specific places.

The aperture can wear a collarette. The apex can wear a mark: in a modest way (a.o. concentric rims, central scar, or a central pit) or more developed forming a mucron (short membranous tube), a copula (long hollow tube), a siphon (bulb-like membranous expansion) or a peduncle (solid structure). The margin of the vesicle can also wear ornamentation: processes (simple or complex spines arranged in a crown on the margin or near the margin) or a carina (circular expansion of the wall present around the chamber above, on or below the margin).

Chitinozoans can occur on four different ways (Paris & Nõlvak, 1999):

1. as loose vesicles scattered in the sediment;

2. as catenary structures where the aperture of one chitinozoan vesicle is connected with the base of the following chitinozoan;

3. as catenary structures with the aperture of the chitinozoan vesicles facing outwards;

4. as "cocoons" with the aperture of the chitinozoan vesicles facing outwards, first illustrated by Kozlowski (1963).

The link between these four different ways of occurrence of the chitinozoans is still not fully understood. But these different ways of occurrence can be partially explained when assuming that chitinozoans are eggs. The chitinozoan animal cannot escape when the opening of the chitinozoan vesicle is not facing outwards. The catenary structures where the aperture is connected with the base of the following chitinozoan represent an immature stage of the chitinozoans. The soft-bodied animal died before the eggs could be placed in the water column (Paris & Nõlvak, 1999). When the chitinozoan vesicles are facing outwards they represent a mature stage.

The chemical composition and the molecular structure of the wall is still not completely known. Study of the chemical composition by means of X-ray diffraction is not possible because the wall is amorphous and hence there is no diffraction. Eisenack (1931) observed that they have a chitin-like appearance and they are resistant to many acids and bases. He supposed that their wall consists of chitin, hence the name chitinozoans. The wall is resistant to warm KOH, warm HF and warm HCl and is corroded by HOCl. Voss-Foucart & Jeuniaux (1972) concluded that they do not consist of chitin, or at least they contain no chitin anymore. The wall of the chitinozoan vesicle is not hydrolised by H_2SO_4 and not coloured by difenol-ZnI, what is the case with chitin. Jacob *et al.* (2007) gave a first clue on the chemical composition of the chitinozoans by study of chitinozoan vesicles by micro-FTIR, laser micro-Raman spectroscopy and laser micropyrolysis-gas chromatography-mass spectrometry. It consists of a kerogen network dominated by aromatic groups with a low contribution of aliphatics and oxygen- or nitrogen-bearing compounds. No chitin is found, confirming the previous findings. Dutta *et al.* (2007) came to the same conclusion, by micro-FTIR and Curie point pyrolysis-gas chromatography-mass spectrometry, that the aromatic compounds predominate over the aliphatic compounds and no pyrolosis products diagnostic of chitin have been detected.

6.2. Systematics

Order Plug	Family Neck differentiation	Sub-family Chamber surface	Genera Chamber shape and arrangement of ornamentation	
OPERCULATIFERA (operculum)	DESMOCHITINIDAE (no neck)	Desmochitininae (glabrous)	lenticular	*Calpichitina*
			spherical	*Hoegisphaera*
			hemispherical	*Bulbochitina*
			conical	*Bursachitina*
			ovoid	*Desmochitina*
			cylindrical	*Ollachitina*
		Cutichitininae (sleeve)	ovoid	*Cutichitina*
		Pterochitininae (carina)	lenticular to spherical	*Pterochitina*
			ovoid (below margin)	*Armoricochitina*
			conical (reticulum, perforated)	*Pseudoclathrochitina*
			conical to ovoid (on margin)	*Cingulochitina*
		Margachitininae (copula)	lenticular to spherical (peduncle)	*Margachitina*
			ovoid	*Urnochitina*
			claviform to cylindrical	*Linochitina*
		Eisenackitininae (spiny)	hemispherical	*Vinnalochitina*
			conical	*Kalochitina*
			conical (with crests)	*Ordochitina*
			ovoid	*Eisenackitina*
		Orbichitininae (processes)	conical	*Orbichitina*
			ovoid	*Armigutta*
			conical to ovoid (sheathing)	*Salopochitina*
PROSOMATIFERA (prosome)	CONOCHITINIDAE (flexure unconspicuous)	Conochitininae (glabrous)	conical	*Euconochitina*
			conical to claviform (with mucron)	*Conochitina*
			claviform	*Clavachitina*
			cylindrical (with widened base)	*Pistillachitina*
			cylindrical	*Rhabdochitina*
		Velatachitininae (sleeve)	claviform	*Velatachitina*
		Eremochitininae (copula)	claviform	*Eremochitina*
			claviform to cylindrical (bulb)	*Siphonochitina*
		Tanuchitininae (carina)	conical to cylindrical (on margin)	*Hyalochitina*
			claviform (below margin)	*Laufeldochitina*
			conical to cylindrical (perforated)	*Baltochitina*
			cylindrical (below margin)	*Tanuchitina*
		Pogonochitininae (carina/spiny)	conical (laciniated, on margin)	*Pogonochitina*
		Belonechitininae (spiny)	conical	*Belonechitina*
			conical to cylindrical (mesh-like)	*Acanthochitina*
			conical (with crests)	*Hercochitina*
		Spinachitininae (processes)	conical to cylindrical	*Spinachitina*
	LAGENOCHITINIDAE (flexure conspicuous)	Lagenochitininae (glabrous)	lenticular to conical	*Saharochitina*
			spherical	*Sphaerochitina*
			ovoid to cylindrical	*Lagenochitina*
		Cyathochitininae (carina)	conical to hemispherical (laciniated)	*Anthochitina*
			conical to hemispherical (perforated)	*Sagenachitina*
			conical to hemispherical (complete)	*Cyathochitina*
			ovoid (reticulum, perforated)	*Parisochitina*
		Pellichitininae (sleeve)	ovoid	*Pellichitina*
		Urochitininae (copula)	ovoid (peduncle)	*Urochitina*
		Angochitininae (spiny)	lenticular to conical	*Fungochitina*
			ovoid	*Angochitina*
			ovoid (mesh-like)	*Muscochitina*
			ovoid (with crests)	*Ramochitina*
		Ancyrochitininae (processes)	lenticular to conical	*Ancyrochitina*
			conical (anastomosed)	*Clathrochitina*
			conical to ovoid (cell-like)	*Plectochitina*
			ovoid to cylindrical (3 crowns)	*Alpenachitina*
			claviform (sheathing)	*Sommerochitina*

Fig. I.6.3. Suprageneric and generic classification of the chitinozoans. From Paris *et al*, 1999.

Chitinozoans are classified in a suprageneric classification with form taxa (see fig. I.6.3), based solely on morphological parameters. The highest classification is "Incertae sedis group Chitinozoa" and subdivided by:

- the presence of either an operculum (Order Operculatifera) or a prosome (Order Prosomatifera) to define the order;

- the presence or absence of a neck and conspicuous or inconspicuous flexure defines the family;

- the presence or absence of ornamentation or other structures on the chamber to define the subfamily;

- the shape of the chamber and the arrangement of the ornamentation to define the genus.

The revised chitinozoan classification of Paris *et al.* (1999) is generally accepted to classify chitinozoans. The authors revised the chitinozoan classification and retained 56 genera of the before 143 earlier described genera. Some of the genera were put into synonymy, others were abondoned or redefined.

6.3. Occurrence

Chitinozoans occur only in marine sediments, from lagoonal environments to basinal environments. They have a planktic or epiplanktic mode of distribution and a lot of species have a wide geographical occurrence. This planktic or epiplanktic mode of distribution is confirmed by the following observations (Paris & Verniers, 2005):

- chitinozoans occur from the undeep shelf to the abyssal plains (but exclusively marine);

- chitinozoans are present, often very abundant, in marine anoxic deposits where benthic fauna is absent;

- distal deposits (outer shelf and slope) yield abundant chitinozoans, whereas acritarchs and/or miospores are rare or virtually lacking;

- the geographical distribution of many chitinozoan species is frequently much wider in comparison with benthic or neritic organisms

- some chitinozoan species occur throughout all the palaeoclimatic belts.

The abundance of chitinozoans is highest on the deep shelf and fine-grained sediments (Paris & Verniers, 2005). The climate plays an important role in the abundance of chitinozoans. The abundance is higher in temperate to polar regions and lower in subtropical to tropical regions. Chitinozoans can resist increased temperature and pressure and they can still be found in rocks which experienced a low degree of metamorphism. It is still possible to obtain chitinozoans from rocks of the greenschist facies as long as the rocks did not experience too much internal deformation (a.o. shear stress).

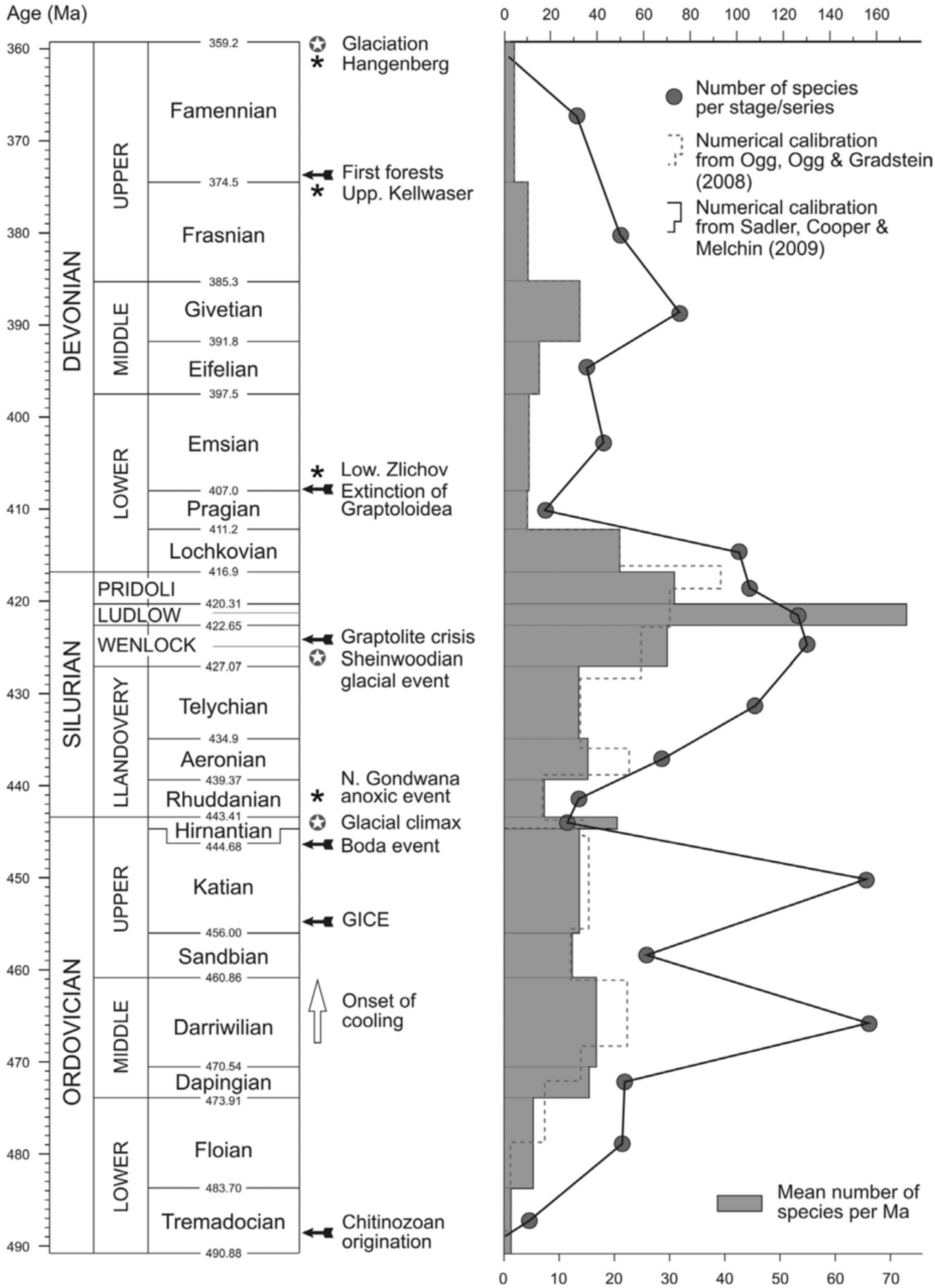


Fig. I.6.4. Global chitinozoan biodiversification curve. The solid circles indicate the number of species per stage (Ordovician and Devonian) or per series (Silurian) with the horizontal scale bar at the top. The graph represents the mean diversity of the chitinozoans per million years for the stages or series (durations based on Sadler *et al.*, 2009) with the horizontal scale at the bottom. An alternative graph (dashed line) is based on the time calibration by Ogg *et al.* (2008). The most significant events are indicated along the time scale. From Grahn & Paris (2011).

The organic wall of the chitinozoans remains elastic for a long time. Hence they are generally flattened by the pressure of the covering sediments (Paris & Verniers, 2005). When lithification happens prior to the compaction three-dimensional chitinozoans can be preserved. Lithologies where this is possibly the case are chert, limestone, phosphatic rock and ironstone.

Early diagenetic pyrite formation in the chitinozoan vesicle can also cause the chitinozoan vesicle to be preserved three-dimensionally.

Interesting to note is the occurrence of chitinozoans by Shen *et al.* (2013) in Cambrian Stage 5, in the Duyun fauna of southern China, and state that the phosphatized fossils are the earliest known chitinozoans, which they assumed a benthic mode of life.

6.4. Biodiversity

Starting from the Tremadocian the chitinozoan diversity (see fig. I.6.4) reaches a first peak in the Darriwillian. This is lowered in the Hirnantian and followed in the Silurian by an increase again with a peak in the Wenlock. After the Wenlock the chitinozoan diversity decreases slightly and starting from the Pragian the chitinozoan diversity is suddenly low until their extinction at the end of the Famennian. Noteworthy is that chitinozoans survived two important extinction events: at the Hirnantian and at the Frasnian-Famennian boundary (the Kellwasser event).

6.5. Application

Chitinozoans are mainly used as biostratigraphic tools for sediments of the Tremadocian up to the Famennian. This is due to their rapid morphological changes through time, their occurrence in a large variety of marine sedimentary rocks and their wide palaeogeographical distribution (Paris & Verniers, 2005).

Although cosmopolitan species exists, many chitinozoan species are palaeogeographic and palaeolatitudinal constrained. In the Ordovician, for example, three major distinct chitinozoan provinces have been recognized corresponding to the three major Ordovician palaeocontinents: Gondwana, Baltica and Laurentia (Achab & Paris, 2007).

In the Late Ordovician Vandenbroucke *et al.* (2010a) proved a latitudinal temperature gradient and Vandenbroucke *et al.* (2010b) detected a shifting of the polar front in the same time slice. Hence chitinozoans are able to play an important role in climate studies and distribution of oceanic water masses, currents and closures of sea ways.

Chitinozoans consist of organic matter and hence contain carbon. They are used to determine stable carbon isotopes (Paris & Verniers, 2005; for example Vandenbroucke *et al.*, 2013).

The colour of chitinozoans is an indication of the palaeotemperature to which the rock was exposed during burial. Also the time duration of exposure to these temperatures plays an important role. Bertrand (1990) constructed a colour-based index to estimate the thermal maturity of the chitinozoans and thus the rock. This colour-based index consists of six colour-classes from yellow to black.

Bertrand (1990) framed a standard for chitinozoan reflectance and correlated this with the reflectance of vitrinite, graptolites and scolecodonts. The reflectance of palynomorphs increases also with thermal maturity. Tricker *et al.* (1992) observed a nearly linear relation between the reflectance of vitrinite and chitinozoan reflectance. They constructed an equation to calculate values of the vitrinite reflectance from the values of the chitinozoan reflectance. Hence chitinozoans can be used to estimate the palaeotemperature.

6.6. Chitinozoan extraction

The chitinozoans are extracted from the samples using standard palynological preparation (treatment with HCl, HF and sieved on a sieve with mesh-size of 53 µm) as described by Paris (1981) and Miller (1996). They were all handpicked and mounted on stubs to study with the Scanning Electron Microscope (JEOL 6400). All the chitinozoans were measured, photographed and identified. We dissolved in our study in most samples between 20 and 35 grams.

6.7. Systematical discussion of the chitinozoan species

In the chapters of Part II the chitinozoans will be discussed following the revised chitinozoan classification scheme proposed by Paris *et al.* (1999). The taxa are listed in the same order as they appear in the latter paper. The dimensions of the chitinozoans are given in micrometers using three numbers with the following meaning and order: the minimum value – the average value – the maximum value. When there are only two specimens present the average value has been omitted; when there is only one specimen present only the value of that specimen is given.

The following abbreviations are used (see fig. I.6.5):

L: total length

Dp: maximal diameter of the chamber

Dc: diameter of the neck

n: number of chitinozoans used for calculation.

Almost all the specimens described are secondarily flattened. The biometric data have not been corrected for flatting. In a seldom case where 3D preservation is present, this is mentioned.

Open nomenclature, if necessary, is used following Bengtson (1988) with “?”, “cf.” and “aff.” used in increasing degree of uncertainty. “?” is an uncertain identification, mostly due to preservation problems; “cf.” is used for a larger degree of uncertainty, mostly caused by preservation problems but sometimes a character is present clearly differing from the description of the type species; “aff.” is used to indicate that the specimen has affinities with a known species, but possesses properties that clearly differs from it.

Only the species in open nomenclature are discussed.

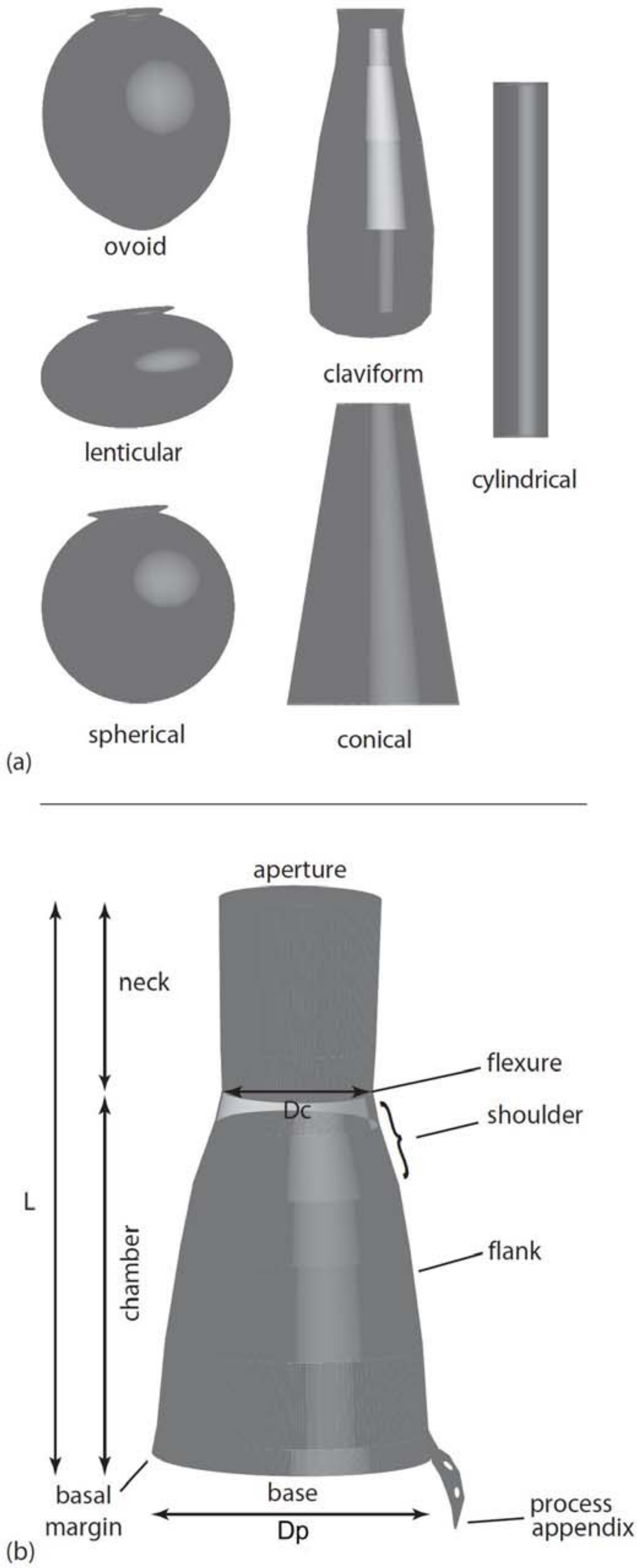


Fig. I.6.5. (a) basic chamber silhouettes of chitinozoans; (b) indication of several of the parameters and morphological features used for the systematical description of chitinozoans. Adapted from Vandenbroucke (2005) and based on Paris *et al.* (1999). All abbreviations are according to Paris (1981).

PART II – Sections of the Condroz Inlier and the Brabant Massif

1. Tihange

1.1. Location

The study area is located in the eastern part of the Condroz Inlier, in the village of Tihange, Huy between Namur and Liège. Four sections are studied: two longer sections with a series of nearly continuous outcrops the rue Bonne Espérance and the rue Rouge Lion, and two smaller sections one along the Ruisseau de l'Homme Sauvage and one in the valley of the ruisseau Sainte-Marguerite (fig. II.1.1.). Two datum points have been created to locate the samples: the northern datum point is at the northern intersection of the rue Bonne Espérance and the rue Rouge Lion; the southern datum point is at the southern intersection of the rue Bonne Espérance and the rue Rouge Lion (fig. II.1.2.).

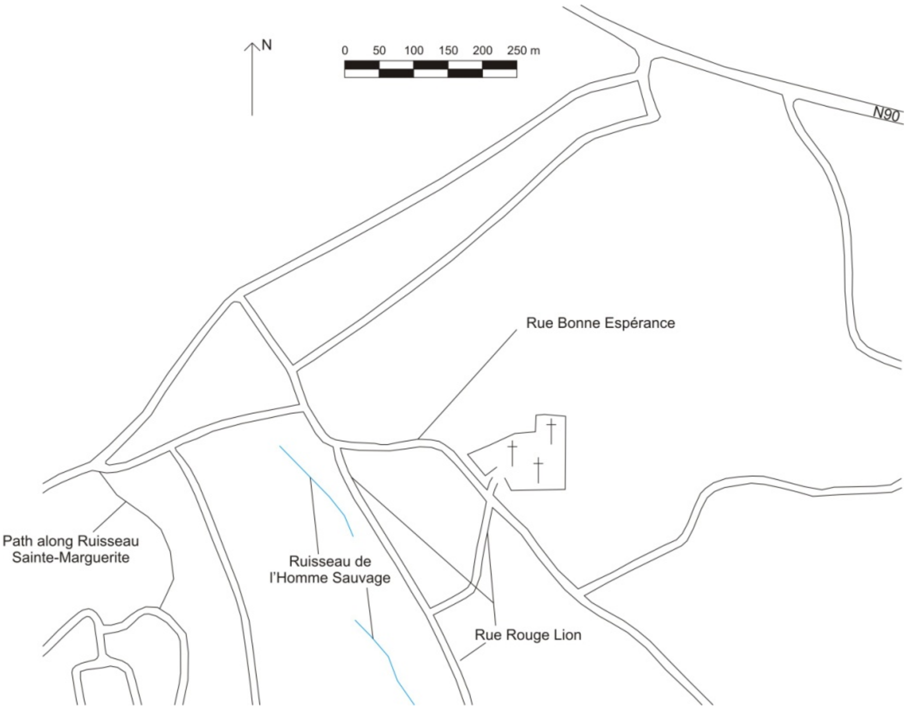


Fig. II.1.1. Map of Tihange with the location of the four sections where outcrops have been studied.

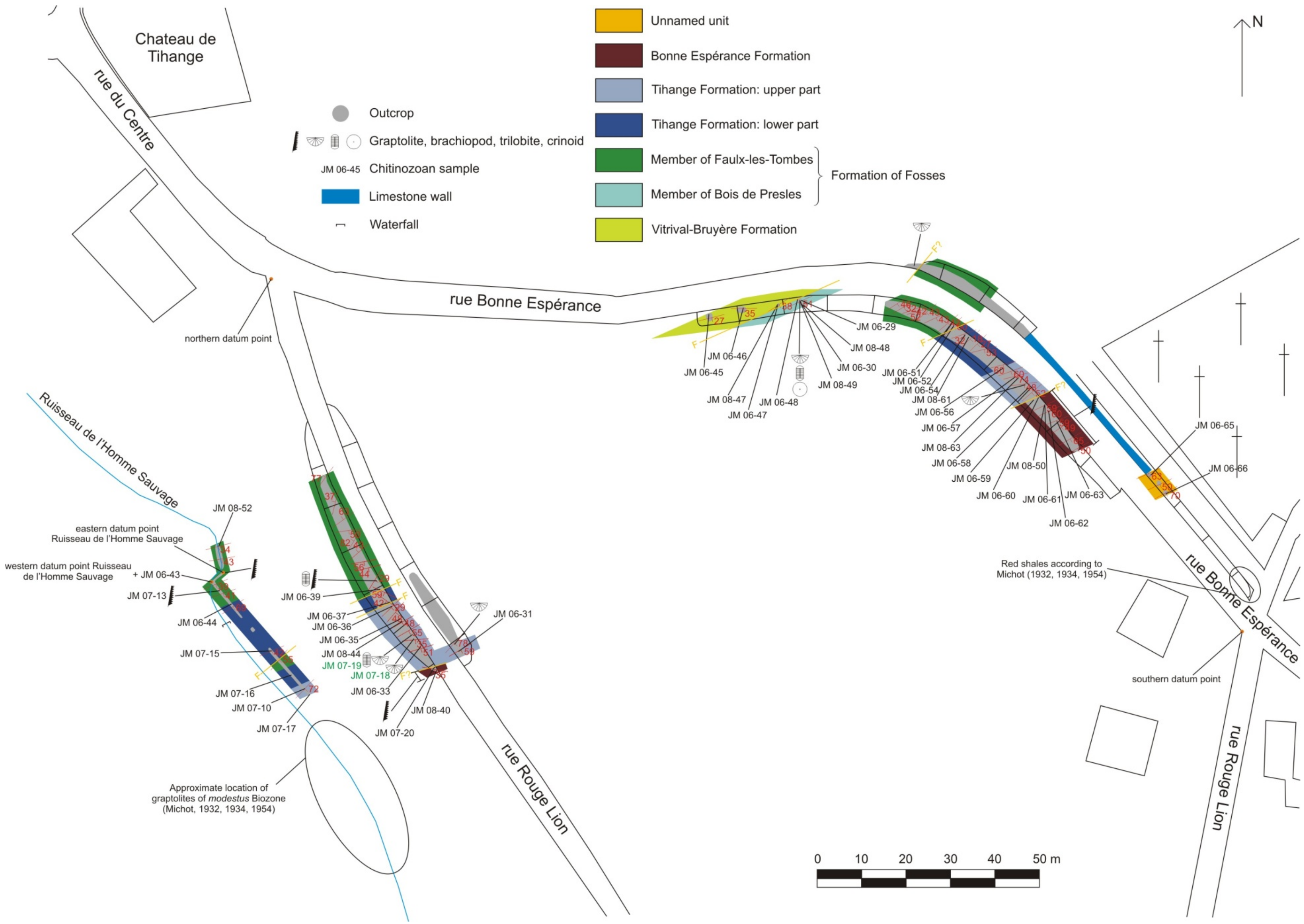


Fig. II.1.2. Overview of the sections of rue Bonne Espérance, rue Rouge Lion and Ruisseau de l'Homme Sauvage.

Along the rue Bonne Espérance the outcrops start from 99.8 m east of the northern intersection of the rue Bonne Espérance and the rue Rouge Lion. These outcrops are small and discontinuous in the approximately east-west part of the street, but around the corner where the road changes to an approximately northwest-southeast direction the outcrop is continuous (starting from 142 m east of the northern datum point). The southeasternmost outcrops at the northeastern part of the street become small and discontinuous again (213-219 m east and southeast of the northern datum point). The outcrops are mainly studied along the southern and southwestern side of the street because of the lack of outcrops are present on the other side of the street and if present the rocks are very weathered except for the southernmost part of the section. The studied section ends at the southern datum point.
Along the rue Rouge Lion the outcrops are mainly studied along its southwestern side. The rocks are outcropping from 45.6 m until 96.7 m southeast of the northern datum point. The northerly outcrops, approximately 19 meters long, are not well exposed and discontinuous.
The outcrops along the Ruisseau de l'Homme Sauvage are mostly present in the bottom of a small gully. Only in the northeastern part the rocks are rather well exposed. More to the south the outcrops become small and discontinuous.
The Ruisseau Sainte-Marguerite has been canalized and flows now mostly underground. However outcrops are still present begin at approximately 120 m southeast of the intersection of the rue du Centre and the path between rue de Centre and avenue Joseph Thonet. From north to south we have first 8.8 meters exposed at the southwestern side followed by 11.5 meters exposed along the northeastern side. The outcrops are well exposed and continuous along both sides.

1.2. Earlier studies

Only the outcrops of the section rue Bonne Espérance and the section rue Rouge Lion have been studied by earlier workers. Malaise (1907) describes in the rue Bonne Espérance grey shale with quartzitic beds, sometimes micaceous, passing into sandstone with traces of fossils. He found brachiopods (*Strophomena rhomboidalis*, *Strophomena siluriana*), a hypostome of a trilobite and an orthocone nautiloid without indicating the exact location. A few meters further, in an east to southeast direction, he found graptolites: *Climacograptus normalis*, *Climacograptus rectangularis* en *Diplograptus* sp. . He could hance conclude that there are two fossiliferous levels: one with brachiopods and the other with graptolites.

Michot (1932a, 1934, 1954) described the outcrops in the rue Bonne Espérance. From base to top he observed the following:

a. Green bluish shale with an intercalated limestone bed, dipping 50° south. In this limestone bed he found *Orthis calligramma* and crinoids.

b. Green, sandy shale and mottled mudstone ("*schistes mouchetés*"), dipping 50° to the south with an estimated thickness of 35 meter.

c. More sandy shale and thin sandstone beds with to the top a few thicker sandstone beds also dipping 50° south with an estimated thickness of 15 meter.

d + e. Green, sometimes very finely laminated shale with the following graptolites: *Cephalograptus acuminatus*, *Mesograptus modestus*, *Climacograptus* sp. This graptolite fauna characterizes the *Cephalograptus acuminatus* Zone. Five to thirteen meters to the south he found in green or black, sometimes finely laminated shales, whitish by weathering the following graptolites: *Mesograptus modestus*, *Orthograptus vesiculosus*, *Climacograptus medius*, *C. rectangularis*, *C. scalaris* var. *normalis*, *Monograptus atavus*, *M. incommodus*. On the western side of the ruisseau de l'Homme Sauvage after some digging he found also in black and grey shale, situated in the continuation of the preceding levels, the following graptolites: *Mesograptus modestus*, *Orthograptus vesiculosus*, *Climacograptus medius*, *C. rectangularis*, *C. scalaris* var. *miserabilis*, *C. Hughesi*, *C. minutus*, *C. scalaris* var. *normalis*, *Dimorphograptus elongatus*. It is indicative for the *Mesograptus modestus* Zone corresponding to the *Orthograptus vesiculosus* Zone..

f. Green or green-black shale, similar to the previous unit.

g. Just before reaching the terrace at 115 meter height red shale outcrops.

He places unit a, b, c in the Fosses Formation and unit d, e, f and g in the Dave Formation (Michot, 1954).

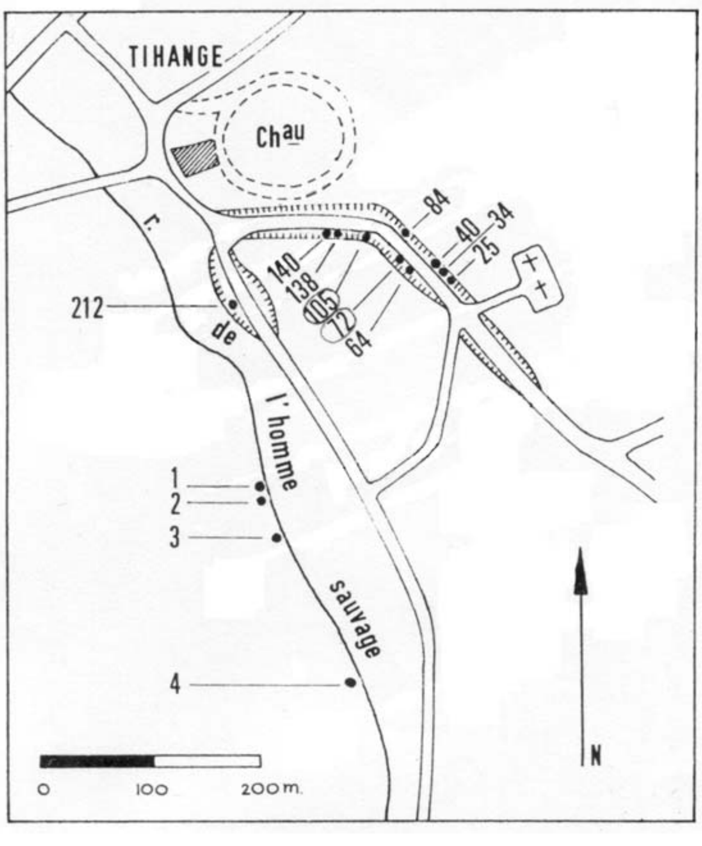


Fig. II.1.3. Map of the sections by Martin (1969a) with the location of the samples. The samples that yield acritarchs are encircled.

Martin (1969a) studied 10 samples of the section rue Bonne Espérance and the section rue Rouge Lion on the acritarch content (fig. II.1.3.). Only two samples contain acritarchs (table II. 1.1.): TIH-105 belongs to the Faulx-les-Tombes Member, Fosses Formation and TIH-72 belongs to the Dave Formation according to Martin (1969a).

Acritarchs	TIH-105	TIH-72
Baltisphaeridium sanpetrensis	X	X
Baltisphaeridium striatulum	X	-
Micrhystridium comatum	X	-
Micrhystridium fragile	X	-
Micrhystridium lobeznum	X	-
Micrhystridium parinconspicuum	X	X
Micrhystridium stellatum	X	-
Veryhachium delmeri	-	X
Veryhachium downiei	X	X
Veryhachium lairdi	X	-
Veryhachium limaciforme	-	X
Veryhachium saccatum	-	X
Veryhachium sartbernardense	X	-
Veryhachium scabratum	X	-
Veryhachium serpentinatum	X	-
Veryhachium trispinosum	X	X
Dictyotidium stenodictyum	-	X

Table II.1.1.: Acritarchs found by Martin (1969a) in the two samples of Tihange that yield acritarchs.

After the work of Martin (1969a) there were some works at the road of the rue Bonne Espérance. The bend in the rue Bonne Espérance has been changed from quite sharp to more gentle. So the location of the samples from previous authors are just approximately known.

The section of Ruisseau de l'Homme Sauvage were graptolites are found from the *modestus* graptolite Biozone (Michot, 1932a, 1934, 1954) is now completely destroyed (filled up with soil) and not visible anymore.

Vanmeirhaeghe (2006b) did a preliminary study of the section rue Rouge Lion and the section rue Bonne Espérance. He described the following units from base to top:

1. In the rue Bonne Espérance at 99.20 to 100.60 m to the east of the northern datum point defined by us he observed dark grey micaceous mud- and siltstone and grey cross-laminated fine-grained sandstone. They belong to the Rue de Courrière Member of the Vitrival-Bruyère Formation.
2. At approximately 122 m east of the northern datum point he observed the Vitrival-Bruyère Formation in fault contact with burrowed brown-grey siltstone, containing

macrofossil(s) (debris), lithologically identical to the Bois de Presles Member. It contains at least two levels with large limestone nodules.

3. At 142 m east of the northern datum point the Faulx-les-Tombes Member occurs. It contains green-grey micaceous siltstone with dark grey elliptical burrows occurring in most of the layers ("*schistes mouchetés*"). In the section rue Rouge Lion it starts to crop out approximately 40 m south of the northern datum point until approximately 75.3 m south of the northern datum point.
4. In the rue Bonne Espérance it is overlain by grey siltstone with some bioturbations and rusty patches along the stratification. Above this occurs fine-grained laminated siltstone and sandstone containing a few thin medium-grained sandstone beds. Higher up grey siltstone overlay these beds. He plave this unit into a new stratigraphical unit, the Tihange Member, belonging to the upper part of the Fosses Formation.
   In the rue Rouge Lion the Faulx-les-Tombes Member gradually passes into grey siltstone with rusty patches. It is overlain by laminated coarse-grained siltstone and fine- to coarse-grained light grey laminated sandstone. Above this grey siltstone occur. All of this is placed into the Tihange Member.
5. There is a sharp contact between the Tihange Member and the covering Bonne Espérance Formation. The latter consists of dark grey to dark green, finely laminated graptolitic mudstone, turning brownish after weathering. Higher up the laminations seem to be less abundant. Some pale clay levels, possibly volcanosedimentary beds, occur in the lower part. In the rue Rouge Lion only the lowermost part is exposed; in the rue Bonne Espérance it occurs from 70 m up to 30 m northwest of the southern datum point. The Bonne Espérance Formation is a newly defined lithostratigraphical unit as it clearly differs from the Dave Formation.

He studied four samples on their chitinozoan content containing very poorly preserved chitinozoans and they are few in number. They do not allow to assign an age to the units.

He proposes an age of lower to middle Katian (Cheneyan to upper Onnian) for the Rue de Courrière Member based on its lithological similarities with the Rue de Courrière Member in Faulx-les-Tombes (Vanmeirhaeghe, 2006a). He deduces an age of middle to late Katian (Pusgillian to early Rawtheyan) analogous to the Bois de Presles Member in Faulx-les-Tombes (Vanmeirhaeghe, 2006a). For the same reason a late Katian (Rawtheyan) age is proposed for the Faulx-les-Tombes Member. A Hirnantian age is suggested for the Tihange Member considering that the top of the Faulx-les-Tombes Member has an age of latest Katian (late Rawtheyan) and the overlying Bonne Espérance Formation has an early Rhuddanian age that is indicated by the graptolites of Michot (1932a, 1934, 1954). Although he cannot exclude a latest Rawtheyan or an earliest Rhuddanian age.

The sections are studied by Mortier (2007) during his M.Sc. thesis with new studies during the PhD study. A part of the results are presented at national and international conferences (Mortier, 2008; Mortier *et al.*, 2009a, 2009b).

1.3. New data

1.3.1. Lithostratigraphy

Fig. II.1.2., II.1.4., II.1.5.

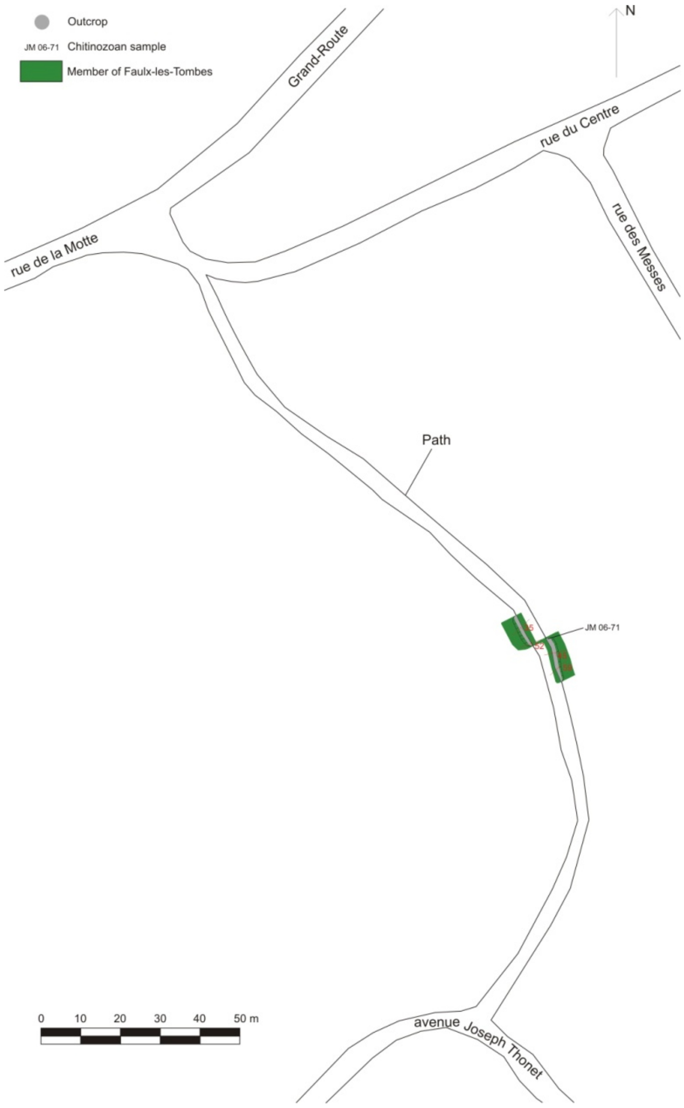


Fig. II.1.4. Map of Ruisseau Sainte-Marguerite

In some discontinuous outcrops going upwards between 99.8 m and 100.7 m, between 106.3 m and 108.5 m, between 115.5 m and 116.1 m and between 120.3 m and 120.9 m eastwards of the northern datum point in the east-west directed part of the section of the rue Bonne Espérance dark grey, micaceous, coarse mudstone occur. The estimated thickness is of at least 2.6 meters. We could not find any macrofossils. It belongs to a not further determined member of the Vitrival-Bruyère Formation as the outcrops are too small to make a distinction possible.

Above this, still in the east-west directed part of rue Bonne Espérance and only present here, brown-grey, decalcified mudstone occurs together with limestone nodules (between 120.3 m and 122.2 m eastwards of the northern datum point). Some levels in the mudstone are coarser than other levels. The limestone nodules contain marcassite. Macrofossils are present (crinoids, brachiopods, trilobites) in the mudstone and many crinoids are present in the limestone nodules. The macrofossils are clearly more present in the coarser layers of the mudstone. The observed thickness is 2.4 meters and it belongs to the Bois de Presles Member of the Fosses Formation. The contact with the underlying lithostratigraphical unit is a fault contact.

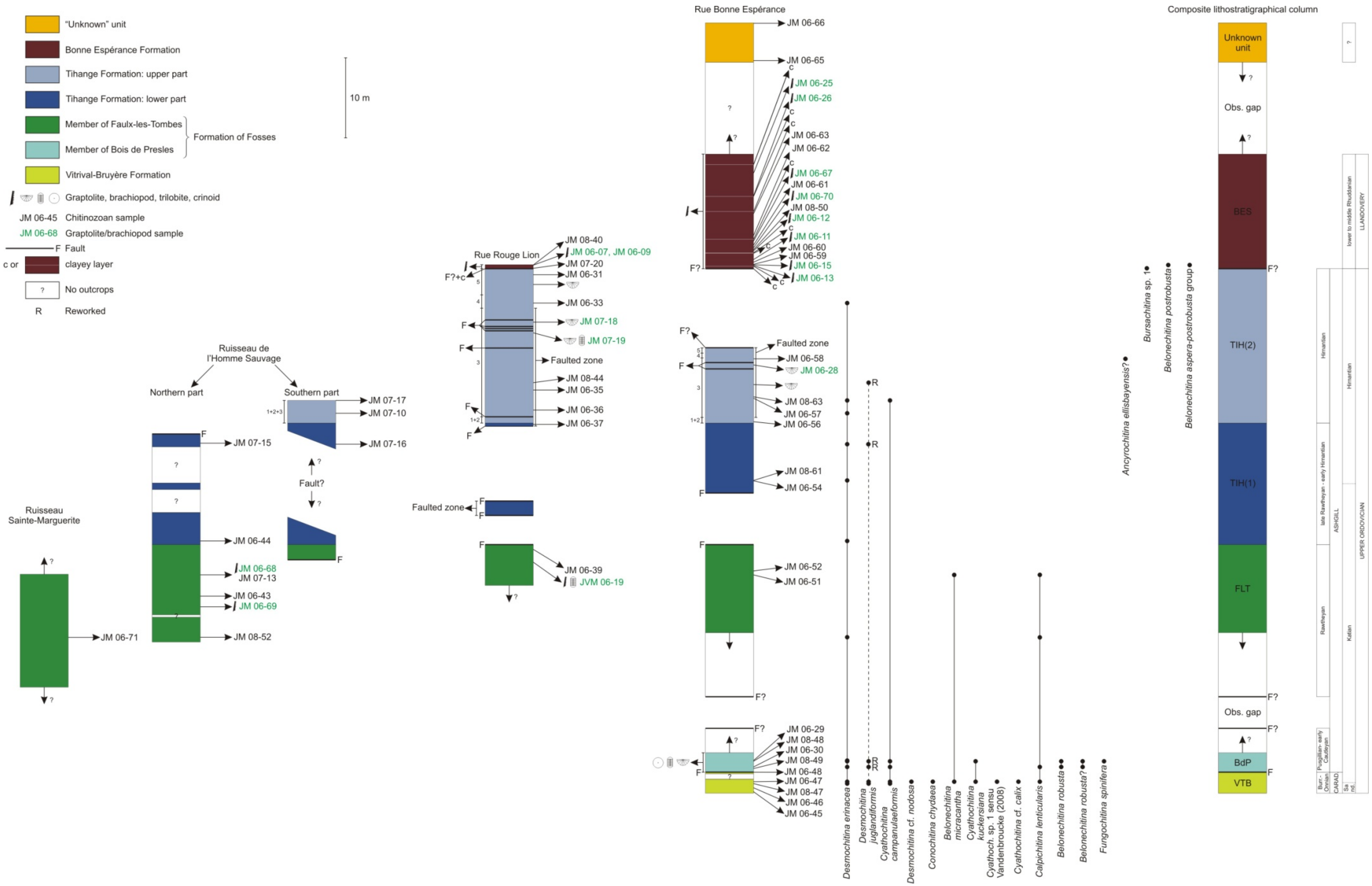


Fig. II.1.5. Lithostratigraphy of the four sections, ranges of selected chitinozoan species, correlation and chronostratigraphy of the four sections of Tihange.

Higher up grey-green, micaceous mudstone occur containing in certain levels dark grey fusiform to elliptic traces of bioturbation, oriented parallel to the bedding. These traces of bioturbation occur only at certain levels and other levels are devoid of them. They were first described by Lassine (1913a) as "*schistes mouchetés*". Locally nodules with a yellow colour, up to 2 cm in size, are present. Towards the top of the unit the facies becomes greyer together with the appearance of little rusty cubics (a maximum of 1 mm), possibly the result of weathered pyrite. This facies belongs to the Faulx-les-Tombes Member of the Fosses Formation occurring in all the four sections but the base has never been clearly observed. In the section rue Bonne Espérance, from 142 m to 160 m eastwards of the northern datum point, we observe at least a thickness of 11 meters but the presence of many small faults make this measurement uncertain. The contact with the covering unit is unclear and possibly by fault. The contact with the underlying Bois de Presles Member is not visible. Brachiopods in the northeastern part of the section rue Bonne Espérance in weathered rocks have been found. The rocks are weathered and it is not clear if it belongs to the Bois de Presles Member or the Faulx-les-Tombes Member. Possibly it is a transitional facies between these two units but this is hypothetical. Hence we located the boundary between these two units there, possibly it is a fault. In the rue Rouge Lion we found a graptolite specimen and a trilobite specimen in one level. In the section rue Rouge Lion this unit occurs from 45.6 to 74.4 m southwards from the northern datum point. The contact with the covering unit is unclear due to poorly exposure but possibly a fault. The thickness is at least 5.1 meter. In Ruisseau de l'Homme Sauvage this lithostratigraphical unit appears twice, both with the stratigraphical contact with the covering unit. In this section it is very clear that the lithology becomes greyer towards the top together with the increasing appearance of rusty cubics and the decreasing presence of the bioturbation traces. We discover here two graptolite levels. The thickness for the northern part is at least 12.2 meter and for the southern part 1.9 meter. In the Ruisseau Sainte-Marguerite only the Faulx-les-Tombes Member is outcropping. The thickness is estimated there at 14.1 meter.

Above the Faulx-les-Tombes Member occurs the Tihange Formation. This latter unit is until now only known from the sections in Tihange and were mentioned for the first time by Vanmeirhaeghe (2006b, 2007b) as the Tihange Member. We propose to elevate this unit to the formation level because of its lithology that is much different from the Fosses Formation. The Tihange Formation can furthermore be divided into two parts: a lower and an upper part.

The lower part contains dark grey, micaceous mudstone of the same grain size as the underlying Faulx-les-Tombes Member with rusty patches occur (1 mm up to 2 cm in diameter). We take the base at the first occurrence of these rusty patches and the frequent occurrence of it. There is however a gradual transition with the underlying lithostratigraphical unit. We could not find any macrofossils. The lower part of the Tihange Formation outcrops in the section rue Bonne Espérance from 160 m to 174 m eastwards of the northern datum point with a thickness of 8.7 meters. The contact with the upper part of the Tihange Formation is a normal stratigraphical contact. In the section rue Rouge Lion, from 74.4 m to 77.8 m southwards of the northern datum point, we measured a thickness of 2.2 meter and the contact with the upper part of the Tihange Formation is also a normal stratigraphical contact but surrounded by faults. In the section Ruisseau de l'Homme Sauvage the lower part of the Tihange Formation occurs two times: in the northern part the thickness is estimated at 13.8

meter with a fault contact at the upper boundary; in the southern part the thickness is estimated at 4.4 meter with a stratigraphical boundary with the overlying upper part of the Tihange Formation. The outcrops are small and not continuous, hampering an exact measurement of the thickness.

The upper part of the Tihange Formation contains five subdivisions. At the base it contains light grey, micaceous mudstones of the same grain size as the lower part of the Tihange Formation (number 1). Upwards it becomes progressively coarser (number 2) to very coarse mudstones to very fine sandstones (number 3) with the occurrence of beds up to 5 cm thick in the coarsest part with cross-bedding (indicating a normal stratigraphical polarity observed in the section rue Bonne Espérance and the section rue Rouge Lion). A lamination become also present when the lithology becomes coarser. Towards the uppermost part the granulometry becomes finer again (number 4) to mudstone with the same grain size as occurring at the base with rare beds of coarser mudstone (a maximum of 3 cm thick; number 5). The rocks become darker grey (not as dark as in the lower part of the Tihange Formation) together with the appearance of rusty patches the same as for the lower part of the Tihange Formation. In the upper part of the Tihange Formation brachiopods (in five levels) and trilobites (in one level) have been found by us. The thickness in the section rue Bonne Espérance for the upper part of the Tihange Formation, present from 174 m to 184 m eastwards of the northern datum point, is 9.4 meter with a possibly fault contact with the covering lithostratigraphical unit. In the section rue Rouge Lion, from 77.8 m to 95.2 m southwards of the northern datum point, the thickness is 19.3 meter again with a possible fault contact as upper limit. In the Ruisseau de l'Homme Sauvage only the basal part is present with a minimal thickness of 2.35 meter.

The uppermost lithostratigraphical unit present is the Bonne Espérance Formation that was only observed in the section rue Bonne Espérance and the section rue Rouge Lion. The name of this unit was mentioned for the first time by Vanmeirhaeghe (2006b, 2007b). Previously it was incorporated in the Dave Formation (original definition by Michot, 1932b; emend. Michot, 1954). The Bonne Espérance Formation contains laminated, dark green to dark grey mudstone, rich in graptolites. However in all sections it is most of the time weathered to a greyish, whitish or brownish colour. Eight white, clay horizons occur parallel with the bedding. They have a thickness of less than 1 centimeter up to 4 centimeter and are possibly volcaniclastic (see fig. II.1.6.). The Bonne Espérance Formation has a thickness of at least 14.3 meter in the section rue Bonne Espérance. In the section rue Rouge Lion only the basal part is present with a minimum thickness of 0.50 meter. At the base of this lithostratigraphical unit in both sections there is white, clay level. It is not clear if a fault exists separating the Bonne Espérance Formation with the underlying Tihange Formation.

Fig. II.1.6. A white, clay level occurring in the Bonne Espérance Formation. As can be seen for this level it consists of multiple white clay levels between brownish rock.

In the uppermost part of the section rue Bonne Espérance dark grey mudstone occur. It can be compact, showing faintly lamination up to clearly laminated. Yellow-green, compact mudstones do also occur. The relationship with the underlying Bonne Espérance Formation is unclear due to an observational gap. The unit differs from the Bonne Espérance Formation by its much less frequent laminations by the presence of yellow-green, compact mudstones. We cannot attribute this unit to an already known lithostratigraphical unit in the Condroz Inlier. Hence we define this as an unnamed unit with an approximate thickness of 4.9 meters.

In all the sections the bedding dips to the southeast to south. Only in the section rue Rouge Lion there is an exception. In the northern part of the Faulx-les-Tombes Member we have besides southeastern dips also northwestern dips, however folds and/or faults are never observed to explain this. This tectonic complexity hampers estimation of the thickness of the unit. In the lower part of the Tihange Member in the section rue Rouge Lion we observe southwestern dips.

1.3.2. Chitinozoan results

A total of 1137 specimens in 43 samples were studied. The chitinozoans are poorly preserved with a total of 16 samples that are barren. The abundance is generally lower than 1 chitinozoan per gram of rock.

Five samples are studied from the Vitrival-Bruyère Formation. Two of them, JM 06-46 and JM 06-48, are barren. The abundance in the other three samples is higher than average. We observed *Desmochitina erinacea*, *D. juglandiformis*, *D.* cf. *nodosa*, *Cyathochitina campanulaeformis*, *C. kuckersiana*, *C.* cf. *calix*, *C.* sp. 1 sensu Vandenbroucke (2008a), *Conochitina chydaea*, *Belonechitina micracantha* and *Calpichitina lenticularis*. The samples JM 06-47 and JM 08-47 are the most abundant with 4.85 and 2.38 chitinozoans per gram of rock respectively.

Four samples are studied from the Bois de Presles Member of the Fosses Formation. Three of them were taken from limestone nodules and one from the mudstone. The sample from the mudstone (JM 08-49) contains no chitinozoans. The three other samples contain *Belonechitina robusta*, *B. robusta*? *Fungochitina spinifera*, *Cyathochitina campanulaeformis*, *C. kuckersiana*, *Desmochitina erinacea*, *Desmochitina juglandiformis* and *Calpichitina lenticularis*.

Eight samples have been studied from the Faulx-les-Tombes Member occurring in all the sections. They all yield chitinozoans: *B. micracantha*, *Desmochitina erinacea* and *Calpichitina lenticularis*.

We have studied eight samples from the lower part of the Tihange Formation, two of them do not contain any chitinozoans. We observed *Desmochitina erinacea* and *D. juglandiformis*.

Eleven samples are studied from the upper part of the Tihange Formation, five of them are barren. We observed *Ancyrochitina ellisbayensis*?, *Cyathochitina campanulaeformis*, *Calpichitina lenticularis*, *Desmochitina juglandiformis*, *Desmochitina erinacea*.

We have studied eight samples from the Bonne Espérance Formation, only three contain chitinozoans. In one of them, JM 08-40, *Belonechitina postrobusta* was encountered together with specimens grouped together in the *Belonechitina aspera-postrobusta* group. In sample JM 07-20 *Bursachitina* sp. 1 does occur.

Three samples are studied from the unnamed unit, unfortunately all of them are barren.

Formation	Member	Sample number	*Conochitina* spp.	*Eisenackitina* spp.	*Desmochitina* spp.	*Spinachitina* spp.	*Desmochitina erinacea*	*Cyathochitina campanulaeformis*	*Desmochitina juglandiformis*	*Belonechitina* spp.	*Lagenochitina* spp.	*Calpichitina* spp.	*Desmochitina* cf. *nodosa*	*Conochitina chydaea*	*Belonechitina micracantha*	*Cyathochitina* spp.	*Bursachitina* spp.	*Hercochitina* spp.	*Cyathochitina kuckersiana*	*Calpichitina lenticularis*	*Cyathochitina* sp. 1 sensu Vandenbroucke (2008)	*Fungochitina* spp.	*Cyathochitina* cf. *calix*	*Belonechitina robusta*	*Belonechitina robusta?*	*Ancyrochitina* spp.	*Fungochitina spinifera*	*Ancyrochitina ellisbayensis?*	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
Unnamed		JM 06-66																												0	20.74	0.00
		JM 06-65																												0	20.10	0.00
Bonne Espérance		JM 06-63																												0	20.49	0.00
		JM 06-62																												0	19.54	0.00
		JM 06-61																												0	25.57	0.00
		JM 08-50																												0	39.40	0.00
		JM 06-60																												0	20.38	0.00
		JM 06-59																											1	1	20.93	0.05
Tihange	TIH (2)	JM 06-58			1																							1		2	20.06	0.10
		JM 08-63			1																								2	3	27.20	0.11
		JM 06-57																												0	20.94	0.00
		JM 06-56																												0	14.67	0.00
	TIH (1)	JM 08-61	2		15		8					3					1	1											11	41	23.52	1.74
		JM 06-54																												0	20.46	0.00
Fosses	FLT	JM 06-52	1																											1	22.45	0.04
		JM 06-51	2		1										1	1													15	20	20.92	0.96
	BdP	JM 06-29	1		1		1									1													4	8	20.79	0.38
		JM 08-48	9	2	28	3	8	2	11	7		5				7	8	2	3					1	4	1	1		63	165	46.61	3.54
		JM 06-30	1	1	11	3	2	2	2	3		1				3				1				1	2				13	46	60.13	0.77
		JM 08-49																												0	30.99	0.00
VTB		JM 06-48																												0	4.12	0.00
		JM 06-47	12	16	78	7	25	2	6	19		4	1	4	5	7	7	2	1	3	1	1	1						99	301	62.11	4.85
		JM 08-47	1	1	14	1	10	1	1	1	1	1																	21	53	22.31	2.38
		JM 06-46																												0	20.83	0.00
		JM 06-45	3	1	1	1																							24	30	20.87	1.44
Total			32	21	151	15	54	7	20	30	1	14	1	4	6	19	16	5	4	4	1	1	1	2	6	1	1	1	253	671	646.13	1.04

Table II.1.2.: Chitinozoan results of rue Bonne Espérance.

Formation	Member	Sample number	*Conochitina* spp.	*Desmochitina* spp.	*Desmochitina juglandiformis*	*Ancyrochitina* spp.	*Calpichitina* spp.	*Spinachitina* spp.	*Desmochitina erinacea*	*Bursachitina* sp. 1	*Bursachitina* spp.	*Belonechitina postrobusta*	*Belonechitina aspera-postrobusta* group	Undetermined chitinozoans	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
BES		JM 08-40										1	5	3	9	20.46	0.44
		JM 07-20	5							9	3			96	113	23.25	4.86
Tihange	TIH (2)	JM 06-31													0	20.70	0.00
		JM 06-33	1	1					2					2	6	20.86	0.29
		JM 08-44	2	14	3	1	2	1						6	29	24.31	1.19
		JM 06-35													0	20.78	0.00
		JM 06-36													0	19.80	0.00
	TIH (1)	JM 06-37		1										10	11	20.13	0.55
Fosses	FLT	JM 06-39												1	1	20.94	0.05
Total			8	16	3	1	2	1	2	9	3	1	5	118	169	191.23	0.88

Table II.1.3.: Chitinozoan results of rue Rouge Lion.

Formation	Member	Sample number	*Belonechitina* spp.	*Desmochitina erinacea*	*Desmochitina* spp.	*Calpichitina* spp.	*Bursachitina* spp.	*Conochitina* spp.	*Cyathochitina* spp.	*Spinachitina* spp.	*Eisenackitina* spp.	*Calpichitina lenticularis*	*Desmochitina juglandiformis*	*Hercochitina* spp.	*Fungochitina* spp.	*Ancyrochitina* spp.	Cyathochitina campanulaeformis	Undetermined chitinozoans	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
Tihange	TIH (2)	JM 07-17	3	4	9		2	7	1	8	3			1	3	1	1	29	72	20.96	3.44
		JM 07-10		1	1					1								4	7	19.94	0.35
	TIH (1)	JM 07-16		1	6	2	1		1	2	1		2					11	27	20.85	1.29
		JM 07-15																2	2	21.04	0.10
		JM 06-44		2	1													5	8	20.14	0.40
Fosses	FLT	JM 07-13	3		7	1		5	2			2						18	38	20.94	1.81
		JM 06-43	2		3			4	2		1							23	35	20.57	1.70
		JM 08-52	3	3	15	3	2	5	2	1	5							47	86	22.10	3.89
Total			11	11	42	6	5	21	8	12	10	2	2	1	3	1	1	139	275	166.54	1.65

Table II.1.4.: Chitinozoan results of Ruisseau de l’Homme Sauvage.

Formation	Member	Sample number	*Desmochitina erinacea*	*Calpichitina lenticularis*	*Desmochitina* spp.	Undetermined chitinozoans	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
Fosses	FLT	JM 06-71	2	1	2	17	22	21.77	1.01

Table II.1.5.: Chitinozoan results of Ruisseau Sainte-Marguerite.

Systematics of the chitinozoans

Incertae sedis group Chitinozoa Eisenack, 1931

Order Prosomatifera Eisenack, 1972

Family Conochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Belonechitinae Paris, 1981

Genus *Belonechitina* Jansonius, 1964

Belonechitina aspera-postrobusta group

Plate II.1.2., specimen 15

Material: 5 specimens in JM 08-40 occuring in the Bonne Espérance Formation, section rue Rouge Lion.

Dimensions: based on 2 flattened specimens; L: 160-189 µm; Dp: 73-89 µm; Dc: 43-47µm.

Description: we refer for the description of both species to Nestor (1980b).

Discussion: Most of the specimens are poorly preserved but they resemble either *Belonechitina aspera* or *Belonechitina postrobusta* when looking at the ornamentation. The base of the specimens is always preserved but is not so convex as in typical *Belonechitina aspera*. The dimensions are too small to be attributed to *Belonechitina postrobusta* and the base is not completely flat as is in typical specimens.

Belonechitina robusta?

Plate II.1.2., specimen 13

Material: 6 specimens in JM 06-30 and JM 08-48 in the Bois de Presles Member, section rue Bonne Espérance.

Dimensions: based on 2 flattened specimens; L: 142-221 µm; Dp: 49-70 µm.

Description: we refer for the description to Eisenack (1959).

Discussion: *Belenochitina* species with the typical *Belonechitina robusta* form. They contain specimens where the ornamentation is partly removed and/or the specimen is not complete. Hence the use of open nomenclature.

Family Lagenochitinidae Eisenack, 1931

Subfamily Cyathochitinae Paris, 1981

Genus *Cyathochitina* Eisenack, 1955b emend. Paris *et al,* 1999.

Cyathochitina cf. *calyx*

Plate II.1.2., specimen 12

Material: 1 specimen in JM 06-47 in the Vitrival Bruyère Formation, rue Bonne Espérance.

Description: we refer for the description to Eisenack (1931 & 1962).

Discussion: The incomplete (broken) nature of the specimen does not allow a firm attribution to the species. Hence open nomenclature is used.

Subfamily Ancyrochitinae Paris, 1981

Genus *Ancyrochitina* Eisenack, 1955a

Ancyrochitina ellisbayensis?

Plate II.1.2., specimen 1

Material: 1 specimen from JM 06-58 in the upper part of the Tihange Formation, section rue Bonne Espérance.

Dimensions: based on 1 flattened specimen; L: 107 µm; Dp: 78 µm; Dc: 38 µm.

Description: we refer for the description to Soufiane & Achab (2000).

Discussion: Only 1 specimen was recovered and only traces of the base of the broken processes are visible. Traces of broken spines on the vesicle wall are also observed. Hence the use of open nomenclature.

Family Desmochitinidae Eisenack, 1931, emend. Paris, 1981

Subfamily Desmochitininae Paris, 1981

Genus *Bursachitina* Taugourdeau, 1966 restrict. Paris, 1981

Bursachitina sp. 1

Plate II.1.2., specimens 5, 6

Material: 9 specimens from JM 07-20 in the upper part of the Bonne Espérance Formation, section rue Rouge Lion.

Dimensions: based on 4 flattened specimens; L: 155-169-186 μm; Dp: 74-84-90 μm

Description: *Bursachitina* species with a completely smooth wall, flat to slightly convex base, rounded basal edge and maximal width 1/3-1/2 of the total length above the base.

Discussion: The presence of an operculum makes is justified to classify them into the *Bursachitina* genus (Paris *et al.*, 1999). A lot of specimens from JM 07-20 could be possibly assigned to this species but are too broken to correctly assign them. Only specimens that were (almost) completely preserved are attributed to this species.

Genus *Desmochitina* Eisenack, 1931

Desmochitina cf. *nodosa*

Plate II.1.2., specimen 3

Material: 1 specimen from JM 06-47 in the Vitrival-Bruyère Formation, rue Bonne Espérance.

Dimensions: based on 1 flattened specimen; L: 81 μm; Dp: 70 μm.

Description: we refer for the description to Eisenack (1931 & 1962) and additional description to Laufeld (1967).

Discussion: Only 1 specimen has been recovered. The collarette is almost not flaring what is typical of true *Desmochitina nodosa* species. But it is possible that the preservation of it was not sufficient. Hence the use of open nomenclature.

Discussion on bio- and chronostratigraphy with chitinozoans

In the Vitrival-Bruyère Formation many of the chitinozoan taxa are long-ranging. *Calpichitina lenticularis* is a typical Gondwana form occurring from the upper Sandbian (upper Soudleyan) to the top of the Ordovician (Paris, 1996). *Desmochitina juglandiformis* occurs from the upper Sandbian (upper Idavere) to the lower Katian (lower Oandu) in Baltica (Nõlvak & Grahn, 1993) with a range more or less parallel to *Spinachitina cervicornis*, but the latter species has not been encountered by us. Vandenbroucke (2008a) found it in British Avalonia from the upper Sandbian (Burrelian) to possibly in the middle Katian (Pusgillian). This means that the part of the Vitrival-Bruyère Formation here has an age ranging from the upper Sandbian (Burrelian) to possibly the middle Katian (Pusgillian).

Fungochitina spinifera is stratigraphically the most important species in the Bois de Presles Member with a total range biozone in Avalonia (Vandenbroucke, 2008b) ranging from the middle Katian (upper Onnian) to the upper Katian (base Cautleyan). It would imply that the Bois de Presles Member would belong to the *Fungochitina spinifera* Biozone. However caution is needed because only one specimen was recovered. No specimens of the easily recognisable *Lagenochitina baltica-prussica* have been found, which would also indicate more that biozone.

The Faulx-les-Tombes Member lacks important proxy chitinozoans that would indicate a precise Biozone. The occurring chitinozoan taxa range throughout most of the Upper Ordovician.

The lower part of the Tihange Formation yields *Desmochitina juglandiformis*. As noted earlier by the range of this species, it would mean that the lower part of the Tihange Formation has an age comparable with that of the Vitrival-Bruyère Formation. We have observed a gradual transition between the underlying Faulx-les-Tombes Member and the lower part of the Tihange Formation and hence to accept that the lower part of the Tihange Formation has an age younger than that of the Faulx-les-Tombes Member. The presence of *Desmochitina juglandiformis* is caused by reworking or indicates that its range extends younger than previously thought.

In the upper part of the Tihange Formation one specimen of *Ancyrochitina ellisbayensis*? occurs. The preservation state of the specimen is not sufficient enough to allow a definite attribution to this taxon. If the specimen belongs to the taxon it would mean that this part of the upper part of the Tihange Formation would belong to the upper part of the Hirnantian (Soufiane & Achab, 2000). The other chitinozoans present do not contradict this age. The occurrence of *Desmochitina juglandiformis* is probably also caused by reworking because we have seen a normal stratigraphical contact between the lower part and the upper part of the Tihange Formation with no signs of any hiatuses. Or the range of this species extends younger than previously thought.

The presence of *Belonechitina postrobusta* in the Bonne Espérance Formation indicates the lower to middle Rhuddanian (Verniers *et al*., 1995). Other specimens present are grouped together into the *Belonechitina aspera-postrobusta* group.

The highest unit, called the unnamed unit, does unfortunately not contain any chitinozoans. Hence it does not allow anything to conclude its age.

1.3.3. Brachiopod results

Brachiopods were found in the upper part of the Tihange Formation in three levels in the section rue Rouge Lion and two levels in the section rue Bonne Espérance. They have been studied in more detail, especially those in the section rue Rouge Lion, in samples JM 07-18 an JM 07-19, by Prof. Dr. David Harper (Durham University, Durham, United Kingdom).

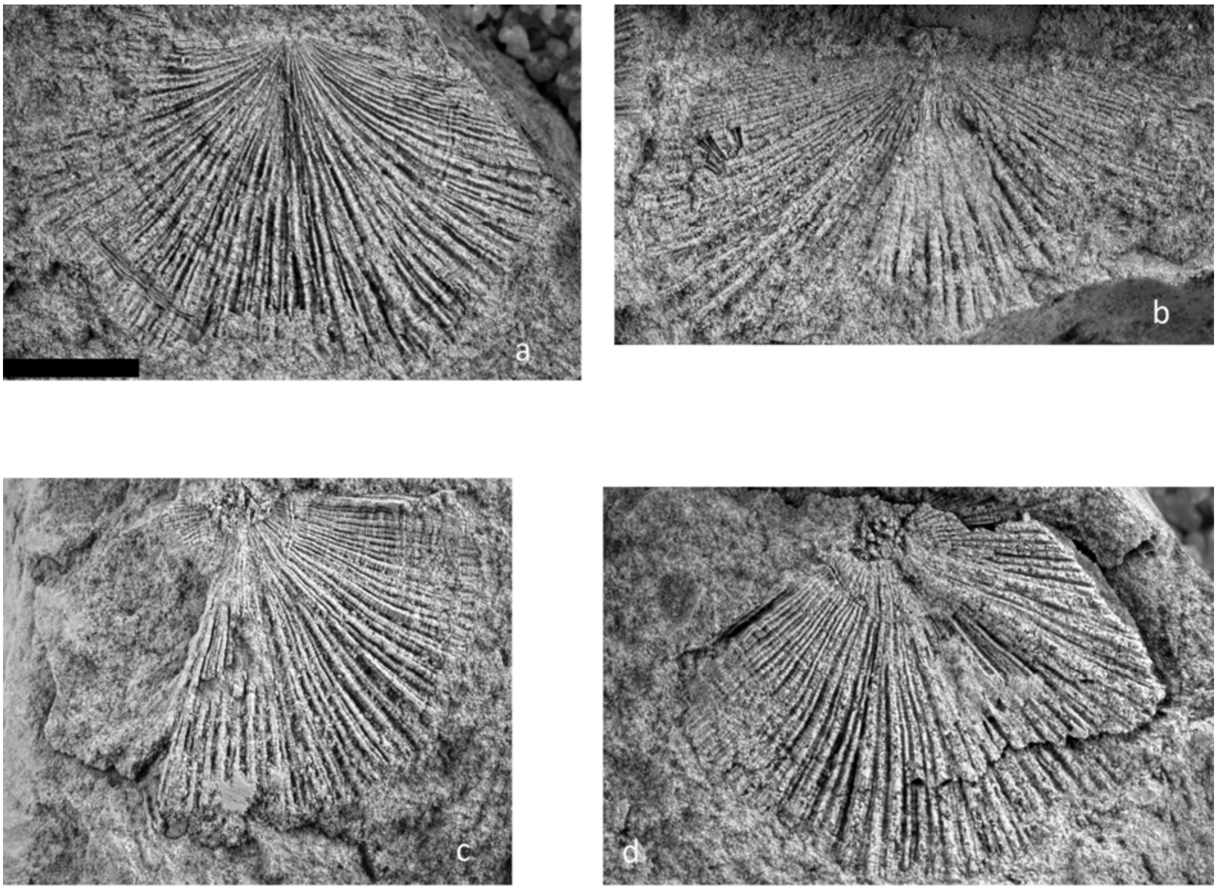


Plate II.1.1. Brachiopods from the upper part of the Tihange Formation. *Eostropheodonta* cf. *hirnantensis*. a. external mould of ventral valve; b. external mould of dorsal valve; c, d. part and counterpart of ventral valve exterior. Scale bar is 5 mm and the same for all pictures.

In his report to the author he writes: the brachiopod fauna, consisting of more than 20 specimens from the two levels in the section rue Rouge Lion, is overwhelmingly dominated by *Eostropheodonta* cf. *hirnantensis* (M'Coy, 1851) together with a few shells of *Plectothyrella*. The assemblage consists mainly of the ventral valves of *Eostropheodonta* characterized by flat profiles in both the dorsal and valves, a transverse to subquadrate outline, together with relatively fine, unequally parvicostellate (multicostellate in larger specimens) ribbing with traces of pseudopunctae developed in the interspaces. The valves generally occur in clusters. Both *Eostropheodont*a and *Plectothyrella* are core members of the late Ordovician *Hirnantia* brachiopod fauna (Bancroft, 1928; Temple, 1965; Bergström, 1968; Wright, 1968) which is currently reported from over 50 localities worldwide (Rong and Harper, 1988). The core group consists of seven key genera, *Cliftonia*, *Dalmanella*, *Eostropheodonta*, *Hindella*, *Hirnantia*, *Leptaena* and *Plectothyrella* and each occurs at over 15 to 25 sites. This near-cosmopolitan fauna characterizes the terminal Ordovician Hirnantian

Stage (Ingham and Wright, 1970) and is usually associated with clastic facies. Rong and Harper (1988) identified three main brachiopod provinces during the Hirnantian. The Bani and Kosov provinces occupied polar to temperate latitudes whereas the Edgewood Province developed across the tropics. *Eostropheodonta* and *Plectothyrella* were particularly common in the Kosov Province which included Avalonia and the classic *Hirnantia* fauna from North Wales. Moreover depth-related gradients within the fauna have been recognized, ranging from shallow-water facies dominated by large *Fardenia*, *Hindella* and *Whifieldella* to the deep-shelf habitats with small *Aegiromena*, *Paromalomena* and *Skenidioides*. *Eostropheodonta* (or its synonym *Aphanomena*) and *Plectothyrella* are most common in shallow-water Benthic Assemblage 3 habitats (Rong and Harper, 1988). Significantly in one of the rare occurrences of the *Hirnantia* fauna in the lowest Rhuddanian, *Eostropheodonta* and *Plectothyrella* are represented by small valves in a probable deep-water refugium on the margin of Avalonia (Harper and Williams, 2002).

This is the first time brachiopods of the *Hirnantia* fauna have been described from Belgium and also the first time brachiopods can be used to assign the upper part of the Tihange Formation to the Hirnantian.

	Position above Tihange Formation (m)	*Parakidograptus acuminatus*	cf. '*Ornagraptus*' *cabanensis*	*Normalograptus parvulus*	*Normalograptus angustus*	*Normalograptus normalis* s.l.	*Diplograptus modestus*	*Dimorphograptus erectus*	Graptolite biozonation
JM 06-25	11,935			??!					*atavus*
JM 06-26	9,115							X	
JM 06-67	3,455					?			*acuminatus*
JM 06-70	2,635					cf.			
JM 06-12	2,245	? aff.							
JM 06-16bis	2,105					cf.	?		
JM 06-11	1,16				cf.				
JM 06-15	0,48			?					
JM 06-09	0,44	?	X						
JM 06-07	0,44	X							

Table II.1.6: Graptolite taxa in the Bonne Espérance Formation. Levels JM 06-07 and JM 06-09 come from the section rue Rouge Lion; the other levels come from the section rue Bonne Espérance. Identifications by Prof. Dr. Jan Zalasiewicz.

1.3.4. Trilobite results

Five trilobite specimens have been found in the section rue Rouge Lion in sample JM 07-19, upper part Tihange Formation. A preliminary study indicate that they belong to the Family Dalmanitidae (Van Roy, pers. comm., 2012).

1.3.5. Graptolite results

We collected graptolites in two lithostratigraphical units: in the Faulx-les-Tombes Member, previously never mentioned before and graptolites have only been found in this unit from the section in Faulx-les-Tombes (Vanmeirhaeghe, 2006a), and the Bonne Espérance Formation. They were identified by Prof. Dr. Jan Zalasiewicz (University of Leicester, Leicester, United Kingdom).

The graptolites of the Faulx-les-Tombes Member belong possibly to *Normalograptus normalis* which does not provide more accurate age of the Faulx-les-Tombes Member.

The identifications of the graptolites from levels of the Bonne Espérance Formation is given in table 1.6. The samples JM 06-07 up to JM 06-67 can be located in the upper part (?) of the *Parakidograptus acuminatus* Biozone. The samples JM 06-26 and JM 06-25 can be located into the *Atavograptus atavus* Biozone. Both biozones indicate an age of early to middle Rhuddanian confirming the assignment by graptolites of Michot (1932a, 1934, 1954).

1.3.6. Discussion

Only chitinozoans were recovered from the Vitrival-Bruyère Formation. The overlying Bois de Presles Member, lower part of the Fosses Formation has an age of the middle to late Katian (Pusgillian to early Cautleyan; see below). We assume that this unit is older than the Bois de Presles Member and the chitinozoans do not contradict this. Together with the chitinozoans it gives an age ranging from the upper Sandbian (Burrelian) up to the middle Katian (Onnian).

The Bois de Presles Member belongs to the *Fungochitina spinifera* Biozone, middle Katian (upper Onnian) to upper Katian (base Cautleyan; Vandenbroucke, 2008b), although this is based on only one specimen of *Fungochitina spinifera*. Vanmeirhaeghe (2006a) found for the Bois de Presles Member in Faulx-les-Tombes an age of middle to late Katian (ranging from the Pusgillian up to the early Rawtheyan). The Bois de Presles Member has never been found to be older than the middle Katian (Pusgillian; Vanmeirhaeghe, 2006b). So we assume an age of middle to late Katian (Pusgillian to early Cautleyan) for the Bois de Presles Member here in Tihange. The specimens of *Desmochitina juglandiformis* found in the Bois de Presles Member are probably reworked specimens as most of them are very poorly preserved.

The Faulx-les-Tombes Member does not yield chitinozoans distinctive for a certain biozone. The type section of the Faulx-les-Tombes Member (Vanmeirhaeghe, 2006a) in the central Condroz Inlier has late Katian (Rawtheyan) age. The chitinozoans present in the Faulx-les-Tombes Member do not contradict this age.

The only fossils found in the rather newly described unit, the lower part of the Tihange Formation, are chitinozoans. On lithostratigraphical arguments it is clear that the lower part of the Tihange Formation is younger than the Faulx-les-Tombes Member of the Fosses Formation, being packed between the Faulx-les-Tombes Member and the upper part of the Tihange Formation. In the Hirnantian a worldwide recognized eustatic sea-level fall has been recognized (Munnecke *et al.*, 2010). The grain size of the lower part of the Tihange Formation is similar to that of the Faulx-les-Tombes Member. So it is probably deposited before the eustatic sea-level fall when we assume that the shelf was not uplifted. An age of late Rawtheyan is expected although an age of late Rawtheyan to early Hirnantian cannot be excluded. The occurrence of *Desmochitina juglandiformis* is most probably caused by reworking.

The presence of brachiopods, typically of the *Hirnantia* brachiopod fauna, in the upper part of the Tihange Formation, gives for the first time in the Condroz Inlier a firm proof of the Hirnantian. The preservation state of *Ancyrochitina ellisbayensis*?, present in one sample as one single specimen, is insufficient to use its presence to corroborate the attribution of the upper part of the Tihange Formation to the upper Hirnantian.

The Bonne Espérance Formation ranges from the upper (?) part of the *acuminatus* graptolite Biozone to the *atavus* graptolite Biozone. This is corroborated by the chitinozoans with the presence of *Belonechitina postrobusta* (Verniers *et al.*, 1995; Butcher, 2009). Hence the Bonne Espérance Formation can be attributed to the lower to middle Rhuddanian.

No fossils have been found until now in the "unnamed" unit. Hence the age of this unit is not known. It cannot be attributed to an already described lithostratigraphical unit.

The thickness variations of the lower part and the upper part of the Tihange Formation in the different sections is probably caused by tectonic fault activity as many faults occur in the sections. Not only in the Tihange Formation faults are observed but also in almost all the other lithostratigraphical units of all the sections.

Michot (1932a, 1934, 1954) mentions the presence of red shales just north of the southern datum point. We could not confirm the presence of this lithology. Red shales are known to occur in the Dave Formation following the definition of Vanmeirhaeghe (2006b) (upper Aeronian to Telychian, middle to upper Llandovery). If the presence of red shales can be confirmed and this would be the same level as these in the Dave Formation a significant time gap would exist between the deposits of the Bonne Espérance Formation and the red shales.

In the Brabant Massif a volcaniclastic layer have been described at the top of the Brûtia Formation, "eurite" of Grand-Manil in the Orneau valley and the "eurite" in the Nivelles area, belonging to the same level and named as Nivelles Member (Delcambre & Pingot, 2002). It has a thickness of 40 m for the "eurite" of Grand-Manil in the Orneau valley (Delcambre & Pingot, 2002) and about 50 m for the "eurite" in the Nivelles area (Mourlon, 1900). Graptolites in the slates below the eurite of Grand-Manil in the Orneau valley indicate the *cyphus* Biozone (Elles in Maillieux, 1930). Graptolite collections in the same levels mentioned in Gerlache (1956) and determined by Bulman (1950) as C. *scalaris* indicate the *acuminatus* Biozone or slightly above or below. Graptolites described within the eurite of Nivelles indicate a *vesiculosus* Biozone according to Rickards in Verniers & Van Grootel, 1991. In a borehole of Deerlijk (in Western Flandres, Belgium) a 1.4 m thick layer possible volcaniclastic origin is described (Legrand, 1966). This layer belongs to the *acuminatus* Biozone and possibly a synchronous volcaniclastic layer as the Nivelles Member at the top of the Brûtia Formation. The volcaniclastic layer present at the top of the Brûtia Formation in the Brabant Massif is much thicker than the multiple centrimetric beds dispersed in the Bonne Espérance Formation in the Condroz Inlier. Multiple volcanic eruptions are recorded in the Tihange section, in contrast with the Brabant Massif where only one is recorded. Both seem to be situated in the lower to middle Rhuddanian. However if they are synchronous and both originating from the same volcanic center, it cannot be proven with our results.

When we consider the model of Vanmeirhaeghe (2006b; see fig. I.4.4) comparing the sediments of the western Condroz Inlier with these of the eastern Condroz Inlier, we can confirm the assumption that sedimentation took place in the Tihange area during the Hirnantian. The brachiopods that have been found in the upper part of the Tihange Formation belong to Benthic Assemblage 3 indicating a position below mean fair weather base but above storm wave base. Hence a bit deeper than proposed by Vanmeirhaeghe (2006b). We confirm that sedimentation was continuous in the Tihange area.

	Puagne Inlier	Bois de Presles section	Arville	Faulx-les-Tombes	Tihange
Faulx-les-Tombes Member	3-5 m	?	≥ 85 m	≥ 66 m	12.2 m-19 m (?)
Bois de Presles Member	~75-95 m	50 m	~23.8 m	31.5 m	2.4 m-5.5 m (?)
Fosses Formation	80-100 m	?	108.8 m	97.5 m	14.6-24.5 m (?)
Faulx-les-Tombes Member (%)	3.8 % - 5 %	?	78.1 %	67.7 %	77.6 % - 83.6 % (observed)
Bois de Presles Member (%)	95 % - 96.2 %	?	21.9 %	32.3 %	16.4 % (observed) - 22.4 %

Table II.1.7: Comparison of the thicknesses of the Bois de Presles Member and the Faulx-les-Tombes Member with other sections from west (left) to east (Tihange) as indicated by Vanmeirhaeghe (2006b). The Arville section is located approximately 3 km west of the Faulx-les-Tombes section. For the Bois de Presles section, located between the villages of Presles and Le Roux, the thickness comes from Michot (1954). A percentage is given for each Member in relation to the total thickness of the Fosses Formation on that location.

Vanmeirhaeghe (2006b) compared the thicknesses of the Bois de Presles Member and the Faulx-les-Tombes Member through the Condroz Inlier. He noticed significantly changes in thicknesses and that the Bois de Presles Member thins towards the east and to the north, whereas the Faulx-les-Tombes Member thins towards the west and probably also to the south (see table 1.7). It is difficult to further extend this hypothesis to the Tihange sections. We see that both the Bois de Presles Member and the Faulx-les-Tombes Member has decreased in thickness. When we take into account the portions of the two members of the Fosses Formation we do not see a significant change in comparison with the sections of Arville and Faulx-les-Tombes. When we take into account the estimated thicknesses the portions are even closer to the sections of Arville and Faulx-les-Tombes. So we cannot extend this hypothesis to Tihange. The Puagne Inlier contains sediments that were deposited significantly further than these of the central Condroz Inlier and were brought together by Variscan tectonics. This is most likely the reason of the thickness variations of the Bois de Presles Member and the Faulx-les-Tombes Member in the Condroz Inlier.

Chitinozoan plate

Plate II.1.2. Chitinozoans from the Tihange sections.

1. *Ancyrochitina ellisbayensis*?. L: 107 µm; Dp: 78 µm; Dc: 38 µm. JM 06-58. Section rue Bonne Espérance. Upper part Tihange Formation.

2. *Belonechitina micracantha*. L: 202 µm; Dp: 85 µm; Dc: 57 µm. JM 06-51. Section rue Bonne Espérance. Faulx-les-Tombes Member, Fosses Formation.

3. *Desmochitina* cf. *nodosa*. L: 81 µm; Dp: 70 µm. JM 06-47. Section rue Bonne Espérance. Vitrival-Bruyère Formation.

4. *Cyathochitina campanulaeformis*. L: 145 µm; Dp: 117 µm. JM 06-47. Section rue Bonne Espérance. Vitrival-Bruyère Formation.

5. *Bursachitina* sp. 1. L: 170 µm; Dp: 85 µm; Dc: 65 µm. JM 07-20. Section rue Rouge Lion. Bonne Espérance Formation.

6. *Bursachitina* sp. 1. L: 186 µm; Dp: 90 µm. JM 07-20. Section rue Rouge Lion. Bonne Espérance Formation.

7. *Desmochitina erinacea*. L: 73 µm; Dp: 64 µm. JM 06-47. Section rue Bonne Espérance. Vitrival-Bruyère Formation.

8. *Desmochitina juglandiformis*. L: 93 µm; Dp: 82 µm. JM 08-48. Section rueBonne Espérance. Bois de Presles Member, Fosses Formation.

9. *Fungochitina spinifera*. L: 95 µm; Dp: 70 µm; Dc: 50 µm. JM 08-48. Section rue Bonne Espérance. Bois de Presles Member, Fosses Formation.

10. *Belonechitina robusta*. L: 265 µm; Dp: 120 µm. JM 08-48. Section rue Bonne Espérance. Bois de Presles Member, Fosses Formation.

11. *Cyathochitina* sp. 1 sensu Vandenbroucke (2008). L: 88 µm; Dp: 72 µm; Dc: 35 µm. JM 06-47. Section rue Bonne Espérance. Vitrival-Bruyère Formation.

12. *Cyathochitina* cf. *calix*. L: 285 µm; Dp: 104 µm; Dc: 63 µm. JM 06-47. Section rue Bonne Espérance. Vitrival-Bruyère Formation.

13. *Belonechitina robusta*?. L: 142 µm; Dp: 68 µm; Dc: 49 µm. JM 06-30. Section rue Bonne Espérance. Bois de Presles Member, Fosses Formation.

14. *Belenochitina postrobusta*. L: 155 µm; Dp: 68 µm. JM 08-40. Section rue Rouge Lion. Bonne Espérance Formation.

15. *Belonechitina aspera-postrobusta* group. L: 160 µm; Dp: 73 µm. JM 08-40. Section rue Rouge Lion. Bonne Espérance Formation.

16. *Calpichitina lenticularis*. Dp: 98 µm; Da: 35 µm. JM 07-13. Section Ruisseau de l’Homme Sauvage. Faulx-les-Tombes Member.

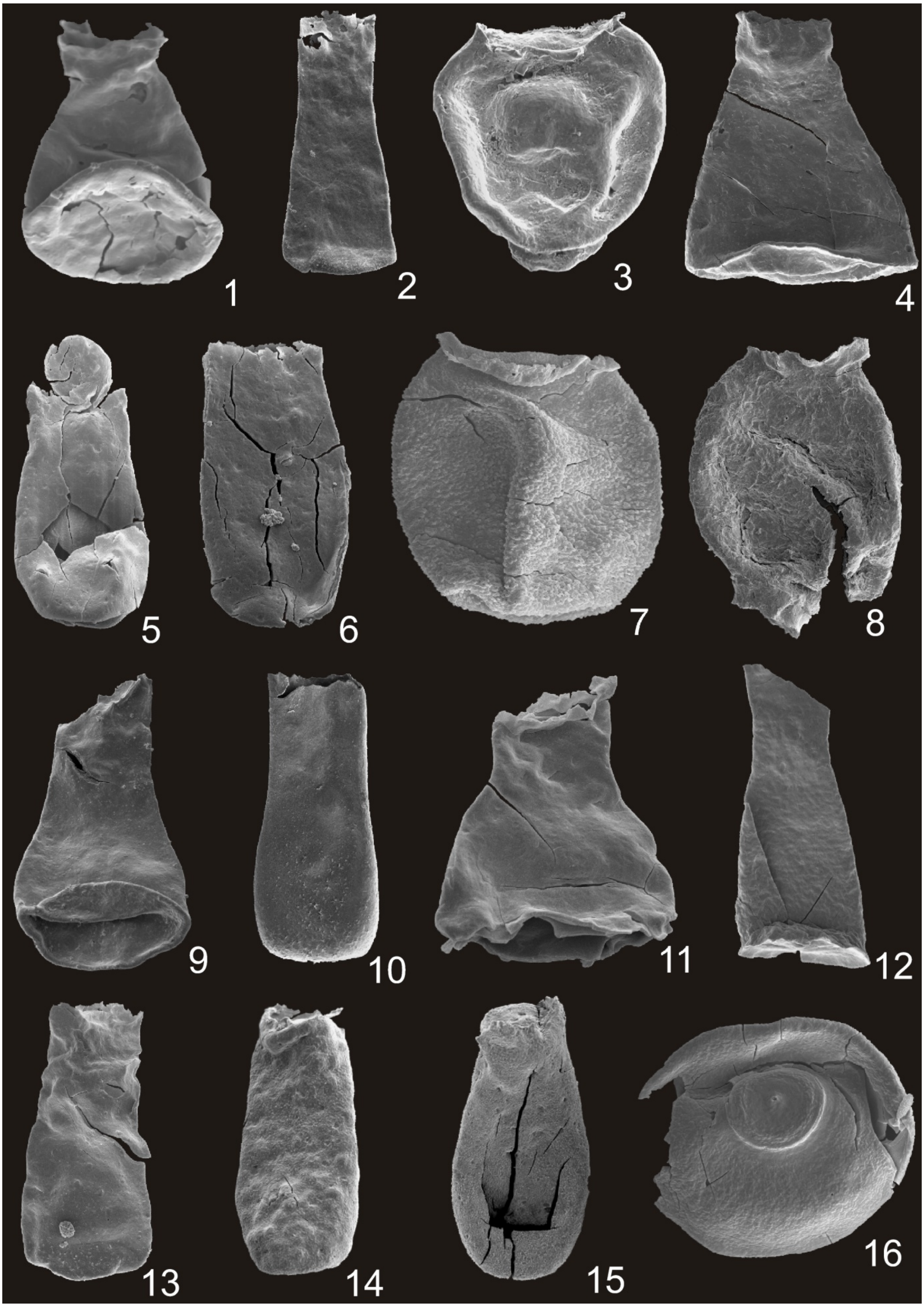


Plate II.1.2.

2. Hennuyères

2.1. Location

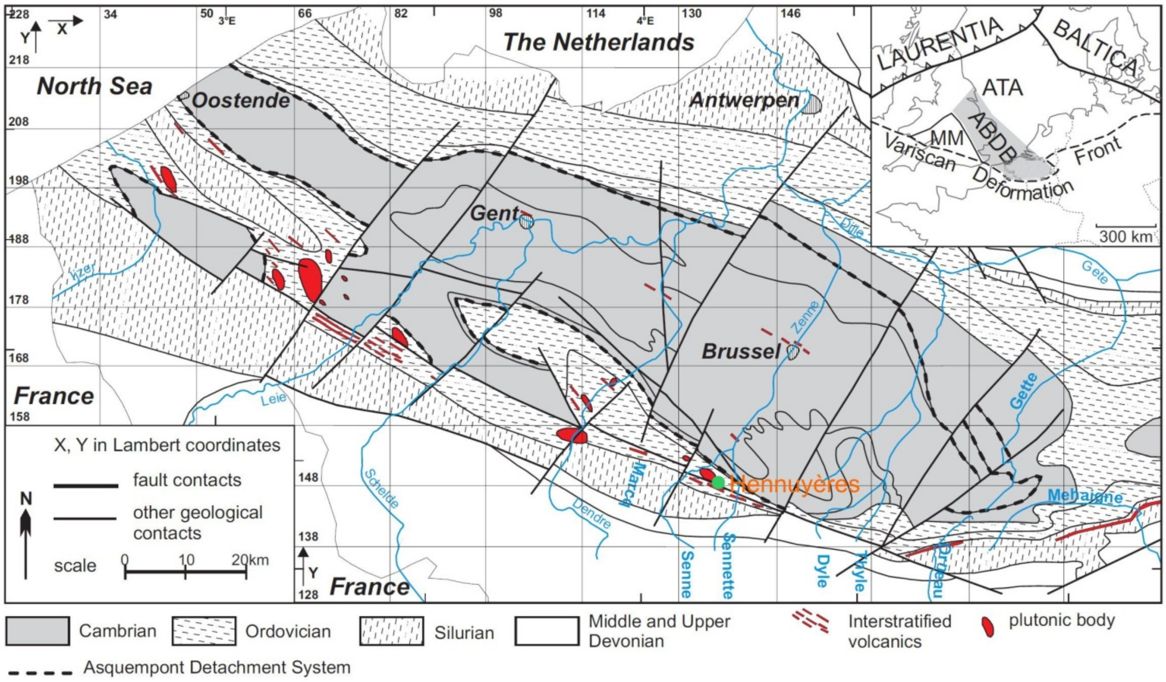


Fig. II.2.1. Geological subcrop map of the Brabant Massif. The location of the study area is indicated with a green dot. Adapted from Debacker, 2012 and after De Vos *et al.* (1993) & Van Grootel *et al.* (1997). The smaller picture at the upper right shows the position of the Anglo-Brabant Deformation Belt (ABDB) within Avalonia (ATA) flanking the Midlands Microcraton (MM).

The outcrops are situated in the topographically lower parts of the valley of the Ruisseau de Coercq, south of the railway station of Hennuyères and north of the centre of Hennuyères (a village part of Braine-le-Comte, Belgium; see fig. II.2.1). We have subdivided the outcrops into five sections (see fig. II.2.2), from northeast to southwest: section 1 formed along the Ri de Coercq northeast of the railway section, section 2 the railway section, section 3 an abandoned quarry east of the railway, section 4 an abandoned quarry west of the railway (mostly filled up and with only the uppermost part visible), section 5 along the rue de Goutteux west of the railway.

2.2. Earlier studies

While mapping for the first geological map of Belgium Dumont (1848) was the first to mention the presence of Palaeozoic rocks in Hennuyères, in a “massif de phyllade” along the new railway. He describes a sandy slate sometimes fossiliferous in Chenois (probably corresponding to our section 4). He also briefly mentions the presence of volcanic rocks which he calls “albite phylladifère”.

Malaise (1865) mentions in a light grey slate in Chenois, near Hennuyères, a specimen of

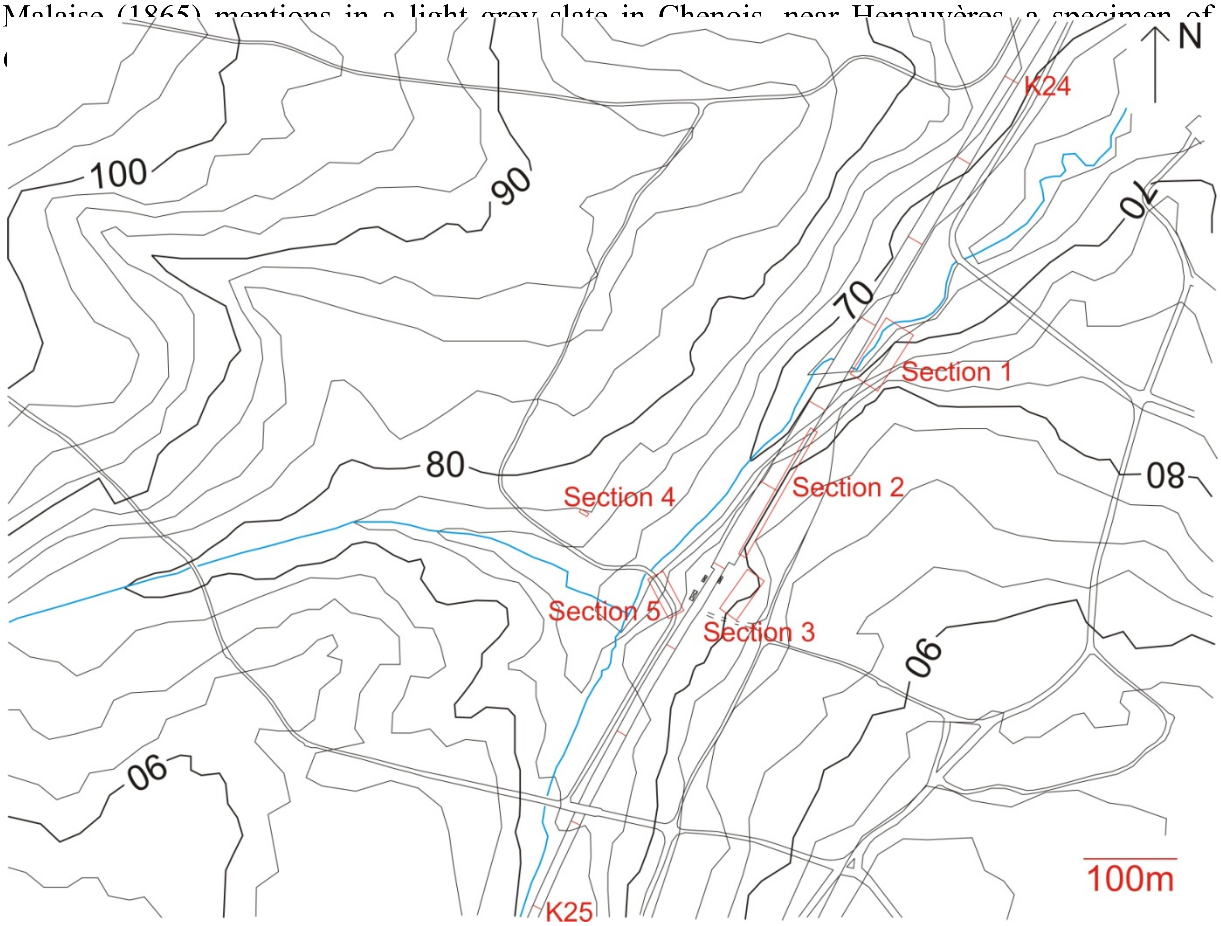


Fig. II.2.2. Map of Hennuyères with the location of the five sections where outcrops have been studied.

Malaise (1873), in his extensive overview of the Ordovician and the Silurian of the Brabant Massif, is mentions the stratified volcanic rocks present in the study area (near Chenois "porphyre schistoide", dipping 65°N). He describes "near the railway", weathered yellowish green-grey slate, dipping 35°N (probably the quarry, called by us section 3). In Chenois, on the left bank of the river, he found an abandoned quarry, used to extract slates (probably the quarry that Dumont mentioned in 1848). The bluish grey slate, with often greyish and bluish patches, is quartz- and pyrite-bearing with a black surface cover, and no clearly marked bedding (68°NE). He found amongst others the following trilobites: *Calymene incerta*, *Trinucleus seticornis*, *Zethus verrucosus*, a cephalon of *Lichas*, which reminds him of the fauna of Fauquez and Grand-Manil.

De la Vallée-Poussin & Renard (1876) remark that the rocks at "Chenois" are only visible in a few beds, mostly very weathered, but still comparable in lithology to the rocks of Fauquez (Madot Formation). They are either slate-bearing albite ("albite phylladifère") a term coined by Dumont, which de la Vallée-Poussin & Renard (1873) renamed as a sericitic slate, and the other lithology is a slaty porphyr ("porphyre schistoide").

Fourmarier (1920) indicated that the volcanic band is much larger than indicated on the detailed geological map and that the "porphyroides" are present over more than 200 m along the railway. He observed two green compact shale intercalations in the altogether weathered magmatic sequence, but could not measure any bedding directions.

Leriche (1924) mentioned during an excursion the rocks in the study area without adding more information.

Mailleux (1926) describes the fauna from the quarry on the left river bank, probably outcrop 4, at Chenois-Hennuyères, one of his five localities of the "lower zone with *Trinucleus seticornis* of the Caradoc" of the Brabant Massif. He indicates crinoids, a brachiopod *Orthis actoniae* and a trilobite *Dalmanella testudinaria. Orthis* mentioned by Malaise (1865) is still in his list, but the four trilobite species mentioned by Malaise (1873) are no more on the list here, but marked as present in the locality of Grand-Manil.

In 1951 the railway was broadened on its eastern side and a 115 m long section, which in our study is referred to as section 2, became available for study. It was described by Legrand, 1951 (see fig. II.2.3). Mortelmans, 1952 (see fig. II.2.4) looked more in detail to the section, and combined the five different parts over 350 m into a combined stratigraphical section of more than 180 m thickness.

Michot (1957), in his overview of the Ordovician and Silurian of Belgium, only mentions the tuffs and tuffites about 100 m thick from Hennuyères.

The magmatic rocks of Hennuyères are also described by Corin (1965) in his extensive overview article on the magmatic rocks of Belgium. He takes over the summary of the detailed work of Mortelmans (1952). He describes the rock in general as coarse-grained tuff, rich in lava debris, intermingled with slate pebbles and broken and corroded crystals of quartz and feldspars. The fine-grained tuff contains mostly debris of quartz and plagioclase in a slaty matrix with microlites identical to those in porphyric lavas. In the tuffs with calcareous cement, this cement is overwhelmingly present together with detritic carbonate particles, which could have had a organic origin. In between the rocks he observed beds that are mostly clastic, sometimes fossiliferous, indicating a marine setting. Hence he concludes that the term tuffite is more appropriate instead of the term tuff. Other beds are real lavas according to him.

Van den haute (1975) focused also on the volcanic rocks present in Hennuyères, besides these present in Rebecq and in Fauquez. The volcanic rocks are detritic and the coarser beds are the product of the degradation of a volcanic mass. In the northern part (corresponding to section 1) recristallized calcite is abundantly present in the volcanic rocks.

The tuffs present at the railway section (section 2) have been dated by Linneman *et al.* (2012) using LA-ICP-MS on zircons. They give a concordant age of 445 ± 2 Ma.

A recent geological mapping campaign (Herbosch *et al.*, 2013) indicated, southwest of the railway station of Hennuyères, the presence of two outcropping lithostratigraphical units: a mainly volcaniclastic unit in the northern part and a unit with green-grey bioturbated mudstone in the southern part. The northern unit was interpreted as the Madot Formation, the southern unit as the lower part of the Brûtia Formation (named as the Goutteux Member by Herbosch & Verniers, 2014), based on general similarity of the facies.

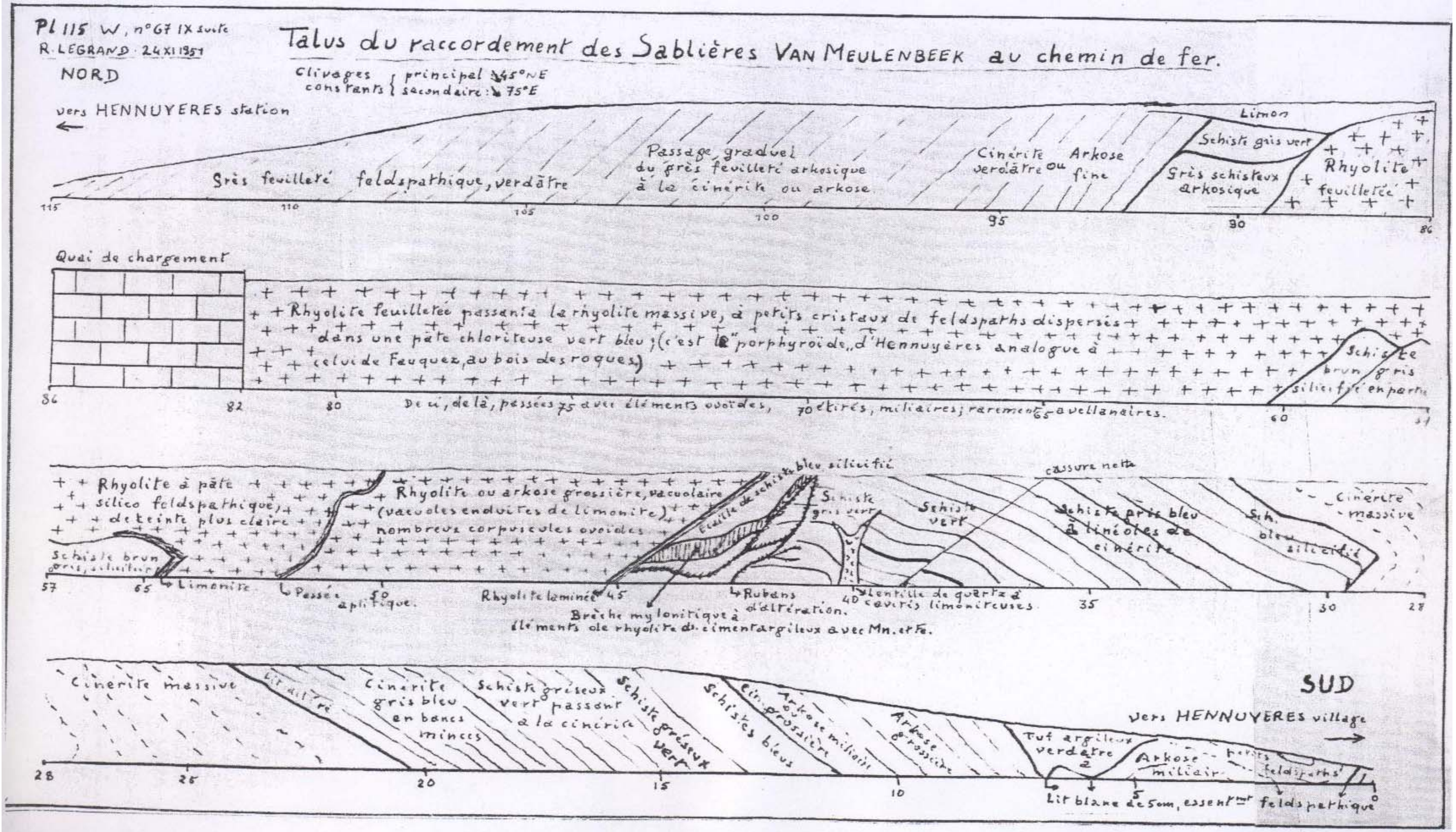


Fig. II.2.3. Section along the railway according to Legrand (1951).

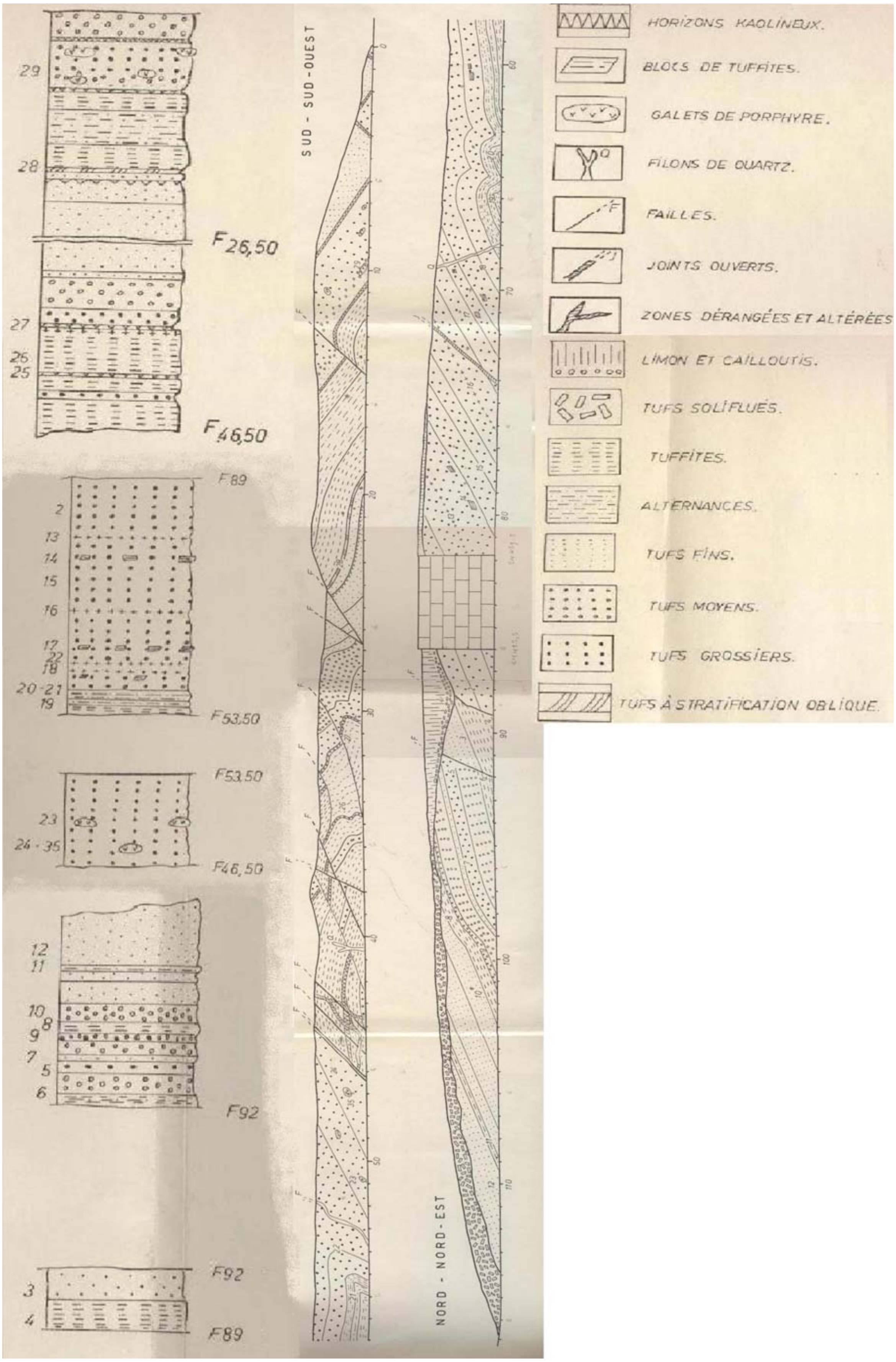


Fig. II.2.4. Section along the railway according to Mortelmans (1952).

The sections are studied by Esselens (2011) during his M.Sc. thesis and reevaluated and restudied during our PhD study. A part of the results are presented at an international conference (Mortier *et al.*, 2012b).

2.3. New data

2.3.1. Lithological results

Section 1

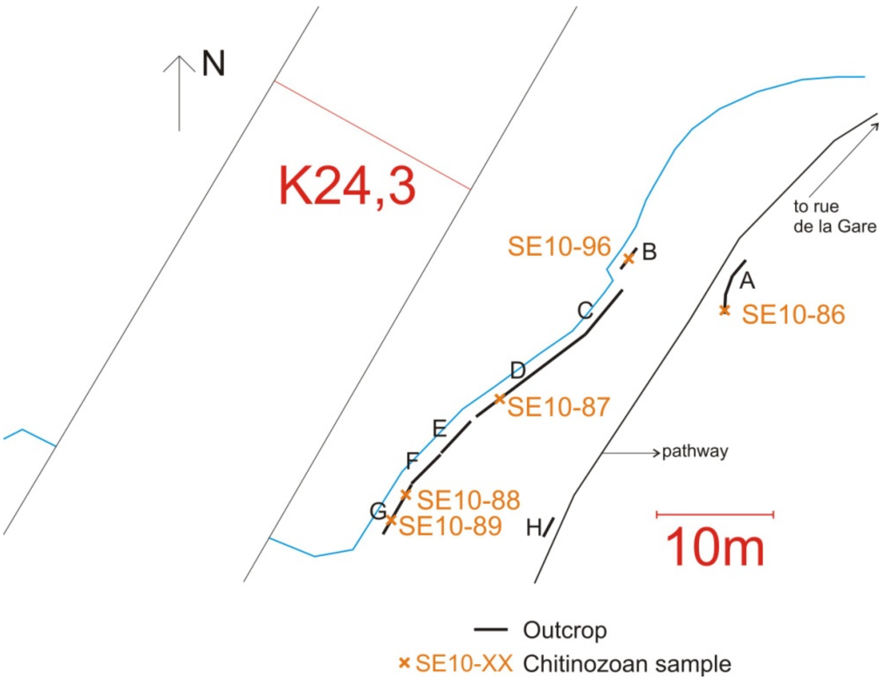


Fig. II.2.5. Map of section 1.

The outcrops of this section are mainly formed along the Ri de Coercq, eastern side, and along a pathway leading northeast to the rue de la Gare (see fig. II.2.5), all located eastwards of the railway. They are all located southwards of K24.3. They are mostly formed by volcaniclastic layers with thin sedimentary beds.

In outcrop A, 5.45 m long, along a pathway, grey, very hard volcaniclastic rock occurs belonging to the sand fraction and poorly sorted. They are calcareous (react strongly with HCl). In the southern part of this outcrop a 15 cm thick layer of dark grey, fine-grained, possibly, a sediment occurs, completely surrounded by volcaniclastic rock (see fig. II.2.6). It does not react with HCl. The bedding of outcrop A dips to the north (Strike 285/Dip 19N) as does the cleavage (Strike 305/Dip 66N).

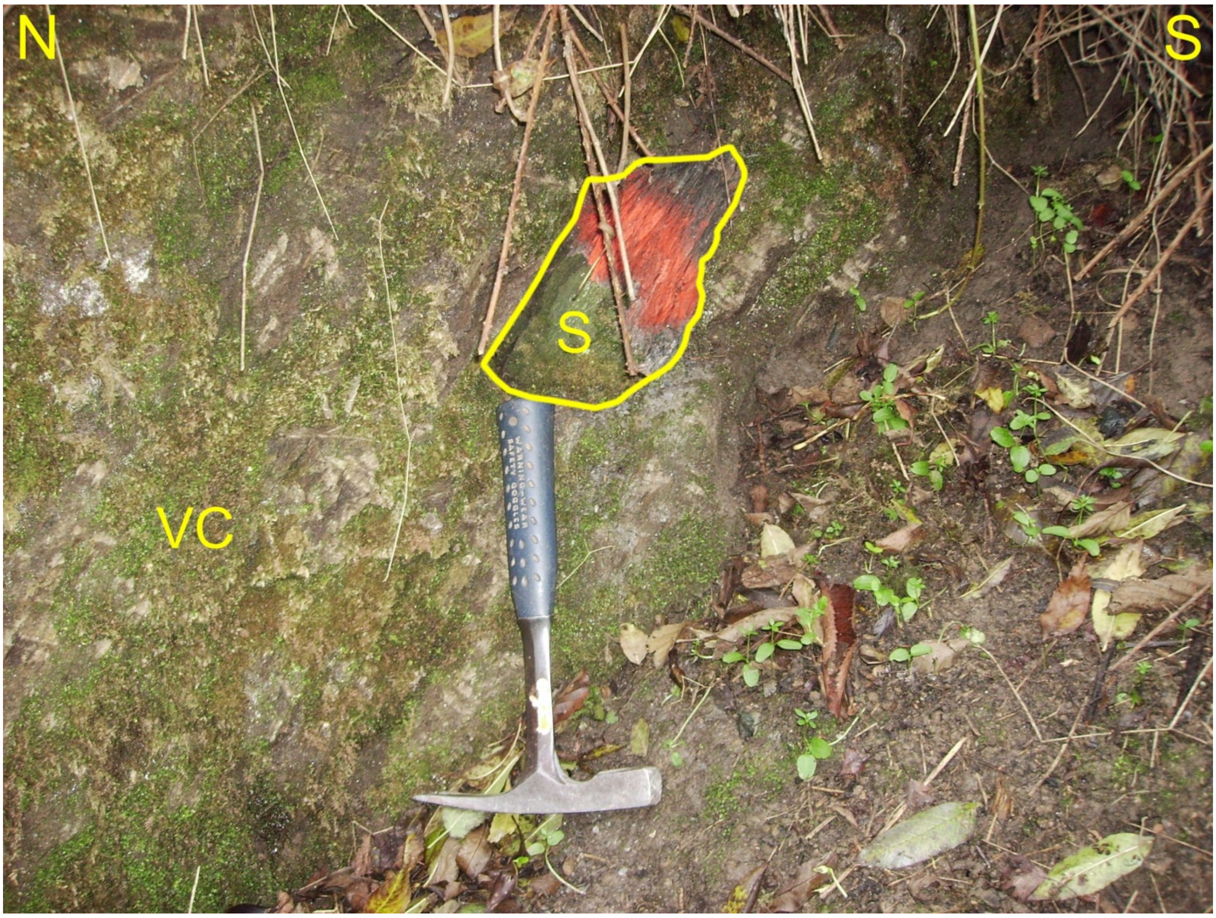


Fig. II.2.6. Sedimentary material (S) completely surrounded by volcaniclastic rock (VC). A chitinozoan sample SE 10-86 has been taken from this material and indicated by red paint on the outcrop.

In outcrop B, along the Ri de Coercq, the same rocks are present as in outcrop A. It occurs at 1.05 m high above the brooklet and with a length at the base of 1.95 m. The cleavage dips to the north (Strike 300/Dip 60N). Also a zone of sedimentary material is present the same as in outcrop A (1.15 m southwards of the northern boundary of the outcrop).

More to the southwest of outcrop B no more outcrops occur or only some loose rocks are visible most probably not in situ (zone C and a big part of zone D).

Starting from the southernmost part of zone D, and more to the southwest outcrops E, F, G, the outcrops are continuous and in situ. The bedding is quite constant with an average of Strike 295/Dip 31N and the cleavage has an average of Strike 296/Dip 55N. They consist of grey to dark grey, thick, hard volcaniclastic layers of the sand to silt fraction intercalated with softer, thinner beds consisting of green-grey, grey to dark grey, fine-grained sedimentary and/or volcaniclastic material, sometimes with rusty patches. Sometimes it is not possible to make a distinction between a sedimentary layer and a volcaniclastic layer. A fining upwards trend is observed in some of the hard volcaniclastic layers indicating a normal polarity. The hard volcaniclastic layers contain sometimes a lot of $CaCO_3$ (seen on the reaction with HCl) although no exact measurements were done to quantify this. This continuous outcrop has a thickness of 7.3 meters.

Section 2

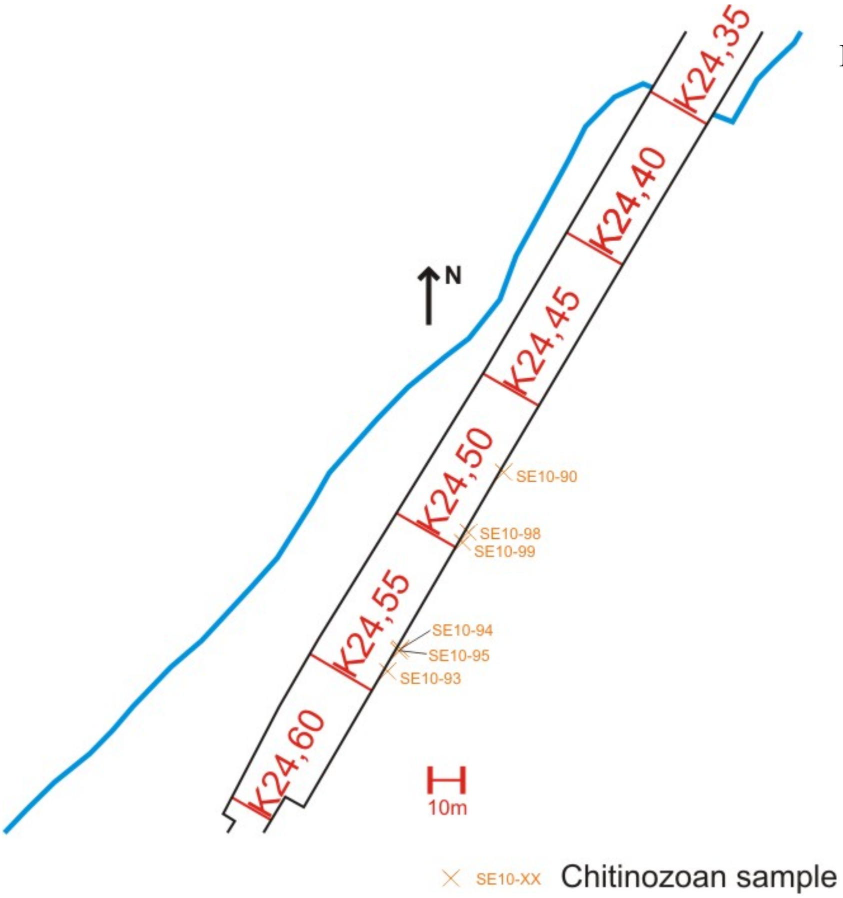


Fig. II.2.7. Map of section 2.

The section is formed along the eastern side of the railway cut (see fig. II.2.7.). It was not possible to make continuous observations due to vegetation cover. Only punctual observations (or along a few meters) could be made. Observations were made on a total length of 139 meter (from K24.427 in the northeast to K24.566 in the southwest).

The rocks are, possible, all volcaniclastic and ranging from coarse-grained (sand fraction) to fine-grained (silt fraction). They are green-grey to grey. On many places rusty patches do occur (possibly weathered crystals or weathered macrofossils). The bedding is varying throughout the whole section although in many cases it was not possible to determine this. In the northern part (from K24.427 to K24.460) the bedding is subvertical. In the southern part (from K24.480 to K24.537) the bedding is to the south with a medium dip. The cleavage is quite constant with an average of Strike 289/Dip 41N. The observations are not continuous, outcrops are small and the bedding is in many cases not found so a section cannot be made.

Section 3

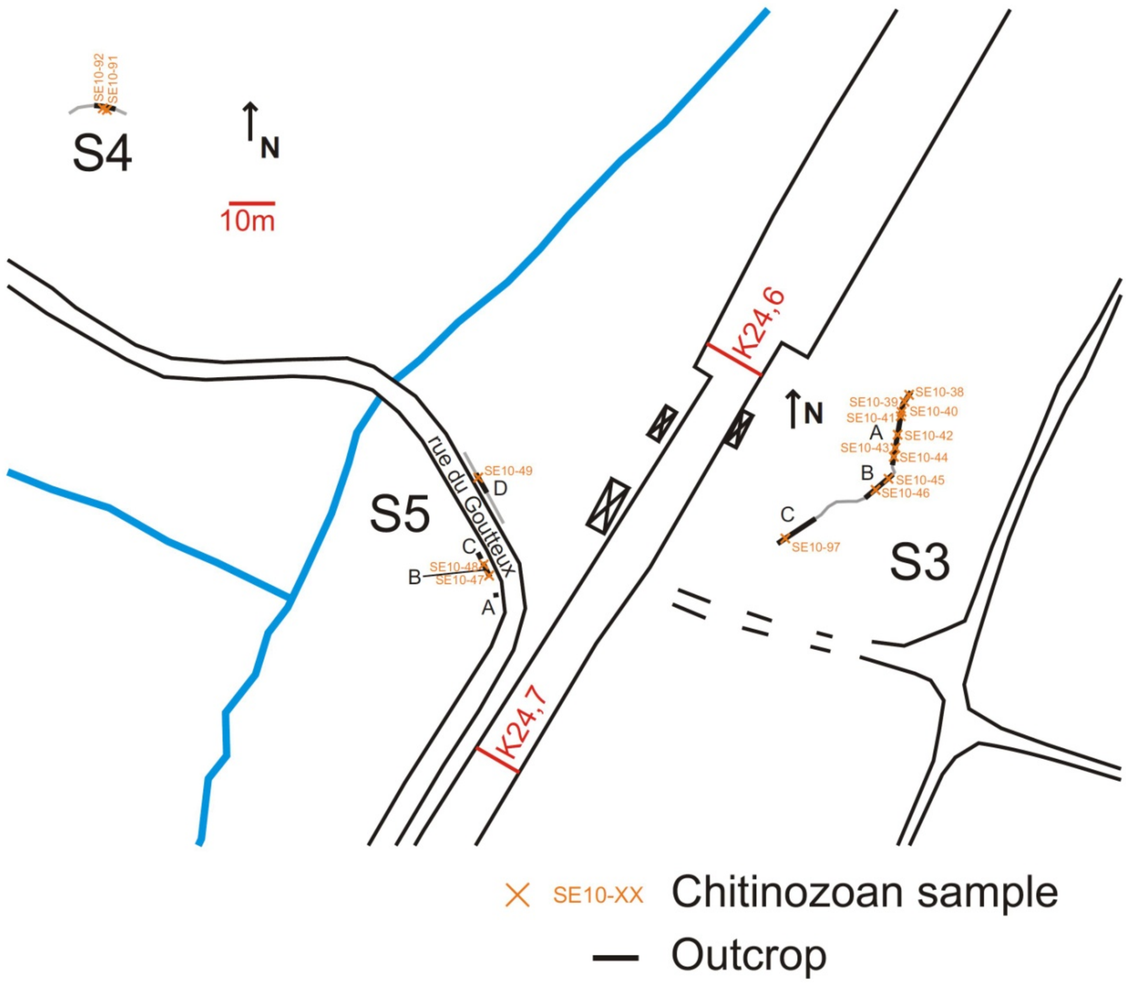


Fig. II.2.8. Map of section 3, 4 and 5.

The section is formed by an abandoned quarry situated east of the railway just south of K24.6. (see fig. II.2.8.) and it can be divided into three parts (part A, B and C).

The lithology is all the same in the entire section: green-grey mudstone, sometimes more grey, with dark grey bioturbations present as fucoids (2-3 mm ellipsoidal bioturbations) and occasionally small rusty patches. Dark grey mudstone do occur without bioturbations but sometimes without following the bedding. The bedding is hardly visible and the cleavage is always clearly present. The bioturbations do not follow always the bedding.

Part A can be divided into two zones: a northern zone 2.2 m long with an orientation of 30°-210° and a southern zone 9.5 m long with an orientation of 10°-190°. In part A the bedding is not clearly visible and the average cleavage is Strike 284/Dip 31N.

Part B is 8 m long and has an orientation of 50°-230°. In part B the average bedding is Strike 162/Dip 12S and an average cleavage of Strike 283/Dip 25N with an estimated thickness of 3 m.

Part C can be divided into two zones: a northern zone 2.55 m long and a southern zone 5.75 m long. Both have an orientation of 55°-235°. In part C the average bedding is Strike 166/Dip 18S and an average cleavage of Strike 291/Dip 21N. A normal polarity has been found and an estimated thickness of 2.5 m. The observational gap between part B and part C has an estimated thickness of 2 m.

As the bedding is not known in part A, we can only say that part B and part C comprise a thickness of 7.5 m.

Section 4

The section is formed by an abandoned quarry situated west the railway (see fig. II.2.8.). The abandoned quarry is now almost completely filled up. Hence only the uppermost part of the quarry is visible.

The section consists of quite strongly weathered rocks (mudstone) with a pale, grey green colour. Bioturbations are present in the same way as in section 3. On some places it is quite rich in macrofossils (crinoids, brachiopods, trilobites), most of the time these macrofossils are weathered leaving holes and rusty patches. It is not possible to determine the bedding due to the small size of the outcrop. The cleavage is Strike 280/Dip 28N.

Section 5

The section is formed along the rue du Goutteux with outcrops situated at the southwestern side and outcrops situated at the northeastern side (see fig. II.2.8.).

At the southwestern side outcrops are visible over a length of 10 m. It consists of green grey to grey mudstone with sometimes rusty patches and holes (possibly caused by the weathering of macrofossils). Bioturbations are present on the same way as in section 4. At the bottom of the outcrop dark grey zones (as dark grey mudstone) are present. The bedding is not clearly visible and the cleavage is Strike 288/Dip 23N.

At the northeastern side dark grey mudstone occurs with some green-grey to grey zones of the same grain size. The relationship between the dark grey and the green-grey to grey mudstones is not clear as they occur at the same level and are sometimes completely mixed. So it cannot be used as a bedding indicator. The bedding is not clearly visible and the cleavage is Strike 287/Dip 17N.

Based on lithostratigraphical arguments we can conclude that the rocks of sections 1 and 2 belong to the Madot Formation, known to include multiple volcaniclastic layers. The rocks of sections 3, 4 and 5 belong to Goutteux Member of the lower part of the Brûtia Formation. Hence we confirm the conclusion of Herbosch *et al.* (2013) to place the rocks into these two lithostratigraphical units.

2.3.2. Biostratigraphy

Formation	Section	Sample number	*Lagenochitina baltica*	*Lagenochitina prussica*	*Tanuchitina* spp.	*Conochitina* spp.	*Conochitina rugata*	*Angochitina* spp.	*Desmochitina* spp.	*Belonechitina* spp.	*Eisenackitina* spp.	*Spinachitina* spp.	*Fungochitina* spp.	*Belonechitina* sp. 1	*Belonechitina wesenbergensis*	*Ancyrochitina* spp.	*Hercochitina* spp.	*Cyathochitina* spp.	*Spinachitina verniersi*	*Spinachitina oulebsiri*	*Cyathochitina kuckersiana*	*Bursachitina* spp.	*Belonechitina* cf. sp. 1	Rhabdochitina spp.	*Desmochitina erinacea*	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
Brûtia	5	SE 10-49								2							9									4	15	35.61	0.42
		SE 10-48																									0	36.69	0.00
		SE 10-47																									0	35.22	0.00
	4	SE 10-91																								4	4	36.50	0.11
		SE 10-92																									0	40.51	0.00
	3	SE 10-97				4				12		13					1	2			1		2	1	1	41	78	38.85	2.01
		SE 10-46																									0	36.83	0.00
		SE 10-45																				1				1	2	36.69	0.05
		SE 10-44																								1	1	36.48	0.03
		SE 10-43																									0	36.40	0.00
		SE 10-42								1		1							1	1	1					5	10	37.42	0.27
		SE 10-41				1																				7	8	35.88	0.22
		SE 10-40				5																				6	11	35.14	0.31
		SE 10-39				5				2		11						3	2							30	53	38.59	1.37
		SE 10-38								1								1								1	3	36.18	0.08
Madot	2	SE 10-93															2										2	46.43	0.04
		SE 10-95																									0	40.56	0.00
		SE 10-94				4		1		4	5	15	2	4	1	1										18	55	40.71	1.35
		SE 10-99		1																						6	7	38.16	0.18
		SE 10-98	1			2			1	1																2	7	43.21	0.16
		SE 10-90	1	2		8	10	1																		13	35	38.31	0.91
	1	SE 10-96																									0	41.26	0.00
		SE 10-86																								1	1	35.78	0.03
		SE 10-87																									0	39.01	0.00
		SE 10-88				2																				3	5	39.82	0.13
		SE 10-89	1	1	1																					1	4	37.03	0.11
Total			3	4	1	31	10	2	1	23	5	40	2	4	1	1	12	6	3	1	2	1	2	1	1	144	301	993.27	0.30

Table II.2.1. Chitinozoan results of Hennuyères.

to moderately well preserved and the abundance is generally lower than 1 chitinozoan per gram of rock (except for three samples with a maximum of 2.01 chitinozoans per gram of rock in one sample). In the Madot Formation 11 samples were treated (three of them are barren) and in the Brûtia Formation 15 samples were treated (five of them are barren). We have obtained a total of 301 chitinozoans (see table II.2.1). The location of the samples are indicated in the figures II.2.4, II.2.6 and II.2.7.

In the Madot Formation in section 1 only ten chitinozoans could be identified in the five samples: a.o. *Lagenochitina baltica* and *L. prussica* occur. In section 2 along the railway the samples are richer in chitinozoans with a total of six samples. The same two species occur next to *Conochitina rugata*, *Belonechitina wesenbergensis* and *Belonechitina* sp. 1.

In the Brûtia Formation in section 3 the highest abundances are encountered with *Spinachitina oulebsiri*, *S. verniersi*, *Cyathochitina kuckersiana*, *Desmochitina erinacea* and *Belonechitina* cf. sp. 1. A total of ten samples are studied from section 3 of which two of them are barren. Section 4, with two samples of which one is barren, contains only 4 chitinozoan specimens (one of the two samples is sterile) which could only be identified as chitinozoans. Two of the three samples of section 5 are barren. The other sample contains *Hercochitina* spp. and *Belonechitina* spp.

Systematic palaeontology of the chitinozoans

Incertae sedis group Chitinozoa Eisenack, 1931

Order Prosomatifera Eisenack, 1972

Family Conochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Belonechitinae Paris, 1981

Genus *Belonechitina* Jansonius, 1964

Belonechitina sp. 1

Plate II.2.1., specimen 7

Material: 4 specimens from SE 10-94, section 2.

Dimensions: L: 110-120 µm (n=2); Dp: 80-93-110 µm (n=4); Dc: 40-51-62 µm (n=4).

Description: a short *Belonechitina* species characterized by a (slightly) convex base, sharp basal edge and straight to slightly convex flanks. It passes upwards into a short cylindrical neck. The spines are small and fine.

Discussion: Only specimens where the spines are distributed over the vesicle wall are attributed by us to this species. Many specimens have the same silhouette but the spines are not (clearly) present or only at the base. These are not attributed to this species.

Belonechitina cf. sp. 1

Plate II.2.2., specimen 6

Material: 2 specimens from SE 10-97, section 3

Dimensions: L: 160 µm (n=1); Dp: 76-105 µm (n=2); Dc: 49-68 µm (n=2)

Description: see *Belonechitina* sp. 1

Discussion: In comparison with *Belonechitina* sp. 1 the spines are more clearly present and a little bit thicker. Although the neck is (partly) broken, the L/Dp ratio is already higher. The base is flat. Hence the use of open nomenclature.

Discussion on bio- and chronostratigraphy with chitinozoans

Many stratigraphically important species do occur.

In section 1 along Ri de Coercq *Lagenochitina baltica* and *Lagenochitina prussica* do occur. They have a comparable range of Onnian (middle Katian) up to middle Rawtheyan (upper Katian; Nõlvak & Grahn, 1993; Vandenbroucke *et al.*, 2005 & Vandenbroucke, 2008a).

Conochitina rugata occurs in one sample in section 2 (sample SE 10-90). In the other samples it is not found. *Conochitina rugata* is an important species as it defines a biozone (Nõlvak & Grahn, 1993; Vandenbroucke, 2008b) corresponding to the total range of the index fossil, possible from the late Cautleyan to definite early Rawtheyan (late Katian). Other species that occur in the section are *Lagenochitina baltica*, *Lagenochitina prussica* and *Belonechitina wesenbergensis*.

The chitinozoans of section 1 and 2, both of the Madot Formation, indicate a chronostratigraphic age of Onnian (middle Katian) to early Rawtheyan (late Katian).

The biostratigraphical data in section 1 does not contradict the age found for the Madot Formation by Vanmeirhaeghe (2006b). He found an age of Pusgillian to Cautleyan (middle to late Katian) in the Sennette valley where the type locality has been defined. The Madot Formation occurring in section 1 and section 2 has an age of the Pusgillian up to the early Rawtheyan.

Ten samples were studied on their chitinozoan content in section 3. Two of them are barren. In two samples *Spinachitina verniersi* was encountered and in one of these *Spinachitina oulebsiri* occurs. They first appear in the late Hirnantian (Vandenbroucke *et al.*, 2009). The presence of *Hercochitina* spp. indicates an age of not younger than the Ordovician (Paris *et al.*, 1999). It means that the rocks in section 3 can be placed in the late Hirnantian.

Section 4 contains only chitinozoans which could not be identified to genus level.

In section 5 *Hercochitina* spp. occurs. It gives an age of not younger than the Ordovician (Paris *et al.*, 1999).

The assemblages of chitinozoans from the different sections (section 3, 4 and 5) in the Brûtia Formation allow to conclude a chronostratigraphic age of late Hirnantian.

2.3.3. Discussion

The presence of the *Conochitina rugata* Biozone is new in the Madot Formation and even for the whole Brabant Massif. It means that the Madot Formation stretches in age up to the early Rawtheyan (late Katian), previously known to occur until the Cautleyan (late Katian; Vanmeirhaeghe, 2006b). Another conclusion is that in Hennuyères volcaniclastic layers are still occurring in the lower Rawtheyan (upper Katian). The age assignment by Linneman (2012) of the volcaniclastic layers along the railway, 445 ± 2 Ma, corroborate the chitinozoan data.

The presence of *Spinachitina oulebsiri* and *Spinachitina verniersi* is new for the Brabant Massif and even for Belgium. For the first time chitinozoans are found, together with *Hercochitina* spp., indicating undoubtedly the upper Hirnantian in the outcrop area of the Brabant Massif.

The presence of *Hercochitina* spp. in section 3 and 5 means that these outcrops, which are the most southern outcrops of the Brabant Massif in the valley of the Ri de Coercq, are limited in age up to the Ordovician (Paris *et al.*, 1999). Only the lower part of the Brûtia Formation, the Goutteux Member, is here cropping out.

In a borehole in Harelbeke, 64 km to the west-northwest of Hennuyères, a similar facies was discovered (Van Grootel, 1995 & Vanmeirhaeghe, 2006b) and defined as Harelbeke unit. It most probably belongs to the Goutteux Member. *Spinachitina taugourdeaui* was encountered and this proved, for the first time, the presence in Belgium of the lower or lower upper Hirnantian in Belgium. This implies that there is a slight overlap of the lower upper Hirnantian of the sediments in the Harelbeke borehole with these of Hennuyères.

The youngest sediments of the Madot Formation are dated as early Rawtheyan. The sediments of the Brûtia Formation present in section 3 have an age of late Hirnantian. The time gap between these two is approximately 2.2 Ma (numerical ages taken from Gradstein *et al.*, 2012). The maximum thickness of sediments not observed between section 2 and section 3 is 17.9 m, when we assume that the beds are vertical dipping. The thickness of the Madot Formation in the Sennette valley is 215 m along the canal section and 290 m west of the canal (Verniers *et al.*, 2005). with an age of Pusgillian to Cautleyan (Vanmeirhaeghe, 2006b) corresponding to 1.8 Ma (numerical ages taken from Gradstein *et al.*, 2012). When we assume the same sediment rate between these two lithostratigraphical units as in the Sennette valley (for the Madot Formation) a fault has to be present between section 2 and section 3 cutting away a part of the sediments.

Chitinozoan plates

Plate II.2.1. Chitinozoans from the Hennuyères sections.

1. *Lagenochitina baltica*. SE 10-89. Section 1. Madot Formation. L: 211 µm; Dp: 149 µm; Dc: 74 µm.

2. *Lagenochitina prussica*. SE 10-89. Section 1. Madot Formation. L: 205 µm; Dp: 165 µm; Dc: 64 µm.

3. *Conochitina* sp. SE 10-88. Section 1. Madot Formation. L: 410 µm; Dp: 95 µm; Dc: 75 µm.

4. *Conochitina rugata*. SE 10-90. Section 2. Madot Formation. L: 195 µm; Dp: 100 µm.

5. *Conochitina rugata*. SE 10-90. Section 2. Madot Formation. L: 230 µm; Dp: 100 µm.

6. *Lagenochitina prussica*. SE 10-90. Section 2. Madot Formation. L: 165 µm; Dp: 128 µm; Dc: 61 µm.

7. *Belonechitina* sp. 1. SE 10-94. Section 2. Madot Formation. L: 140 µm; Dp: 110 µm; Dc: 62 µm.

8. *Eisenackitina* sp. SE 10-94. Section 2. Madot Formation. L: 130 µm; Dp: 95 µm; Dc: 60 µm.

9. *Belonechitina wesenbergensis*. SE 10-94. Section 2. Madot Formation. L: 205 µm; Dp: 97 µm; Dc: 54 µm.

10. *Conochitina* sp. SE 10-94. Section 2. Madot Formation. L: 127 µm; Dp: 80 µm; Dc: 35 µm.

11. *Spinachitina* sp. SE 10-39. Section 3. Brûtia Formation. L: 170 µm; Dp: 70 µm; Dc: 55 µm.

12. Detail of plate 1, picture 11 showing the base of Spinachitina sp..

13. *Spinachitina* sp. SE 10-39. Section 3. Brûtia Formation. L: 140 µm; Dp: 80 µm; Dc: 45 µm.

14. *Spinachitina verniersi*. SE 10-39. Section 3. Brûtia Formation. L: 165 µm; Dp: 75 µm; Dc: 47 µm.

15. Detail of plate 1, picture 14 showing the base of *Spinachitina verniersi*.

16. *Spinachitina* sp. SE 10-39. Section 3. Brûtia Formation. L: 235 µm; Dp: 75 µm; Dc: 50 µm.

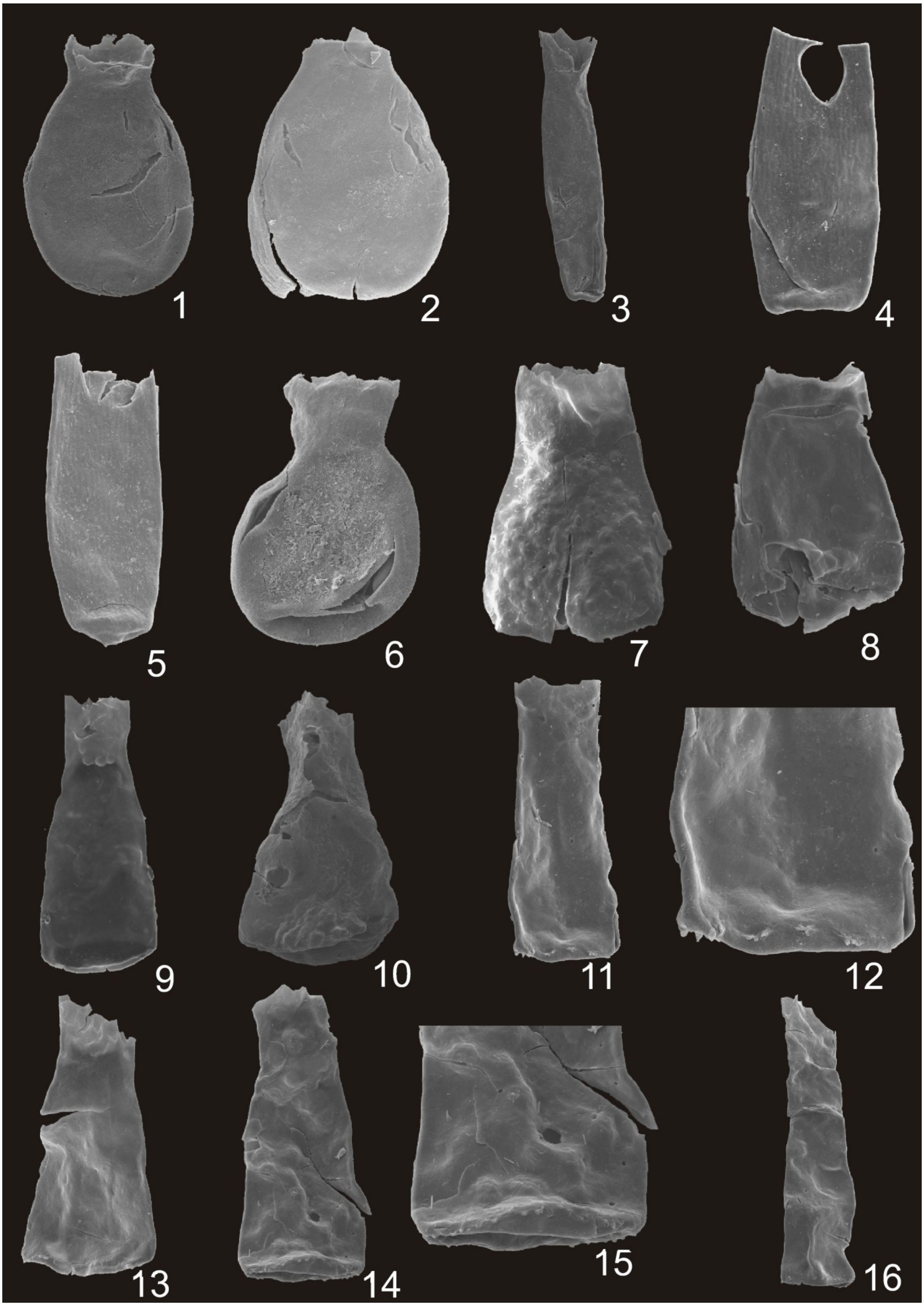


Plate II.2.1.

Plate II.2.2. Chitinozoans from the Hennuyères sections.

1. *Spinachitina* sp. SE 10-39. Section 3. Brûtia Formation. L: 98 µm; Dp: 73 µm; Dc: 38 µm.

2. *Conochitina* sp. SE 10-41. Section 3. Brûtia Formation. L: 180 µm; Dp: 100 µm; Dc: 60 µm.

3. *Spinachitina oulebsiri*. SE 10-42. Section 3. Brûtia Formation. L: 210 µm; Dp: 85 µm; Dc: 45 µm.

4. Detail of plate 2, picture 3 showing the base of *Spinachitina oulebsiri*.

5. *Bursachitina* sp. SE 10-45. Section 3. Brûtia Formation. L: 145 µm; Dp: 78 µm; Dc: 42 µm.

6. *Belonechitina* cf. sp. 1. SE 10-97. Section 3. Brûtia Formation. L: 120 µm; Dp: 78 µm; Dc: 49 µm.

7. *Rhabdochitina* sp. SE 10-97. Section 3. Brûtia Formation. L: 550 µm; Dp: 100 µm; Dc: 70 µm.

8. *Hercochitina* sp. SE 10-97. Section 3. Brûtia Formation. L: 145 µm; Dp: 90 µm; Dc: 48 µm.

9. *Spinachitina* sp. SE 10-97. Section 3. Brûtia Formation. L: 132 µm; Dp: 76 µm; Dc: 42 µm.

10. *Spinachitina* sp. SE 10-97. Section 3. Brûtia Formation. L: 115 µm; Dp: 70 µm: Dc: 40 µm.

11. *Desmochitina erinacea*. SE 10-97. Section 3. Brûtia Formation. L: 86 µm; Dp: 76 µm.

12. *Cyathochitina* sp. SE 10-97. Section 3. Brûtia Formation. L: 273 µm; Dp: 90 µm; Dc: 52 µm.

13. *Belonechitina* sp. SE 10-97. Section 3. Brûtia Formation. L: 140 µm; Dp: 75 µm; Dc: 40 µm.

14. *Belonechitina* sp. SE 10-97. Section 3. Brûtia Formation. L: 190 µm; Dp: 90 µm; Dc: 60 µm.

15. *Conochitina* sp. SE 10-97. Section 3. Brûtia Formation. L: 215 µm; Dp: 80 µm; Dc: 50 µm.

16. *Belonechitina* sp. SE 10-49. Section 5. Brûtia Formation. L: 280 µm: Dp: 100 µm; Dc: 60 µm.

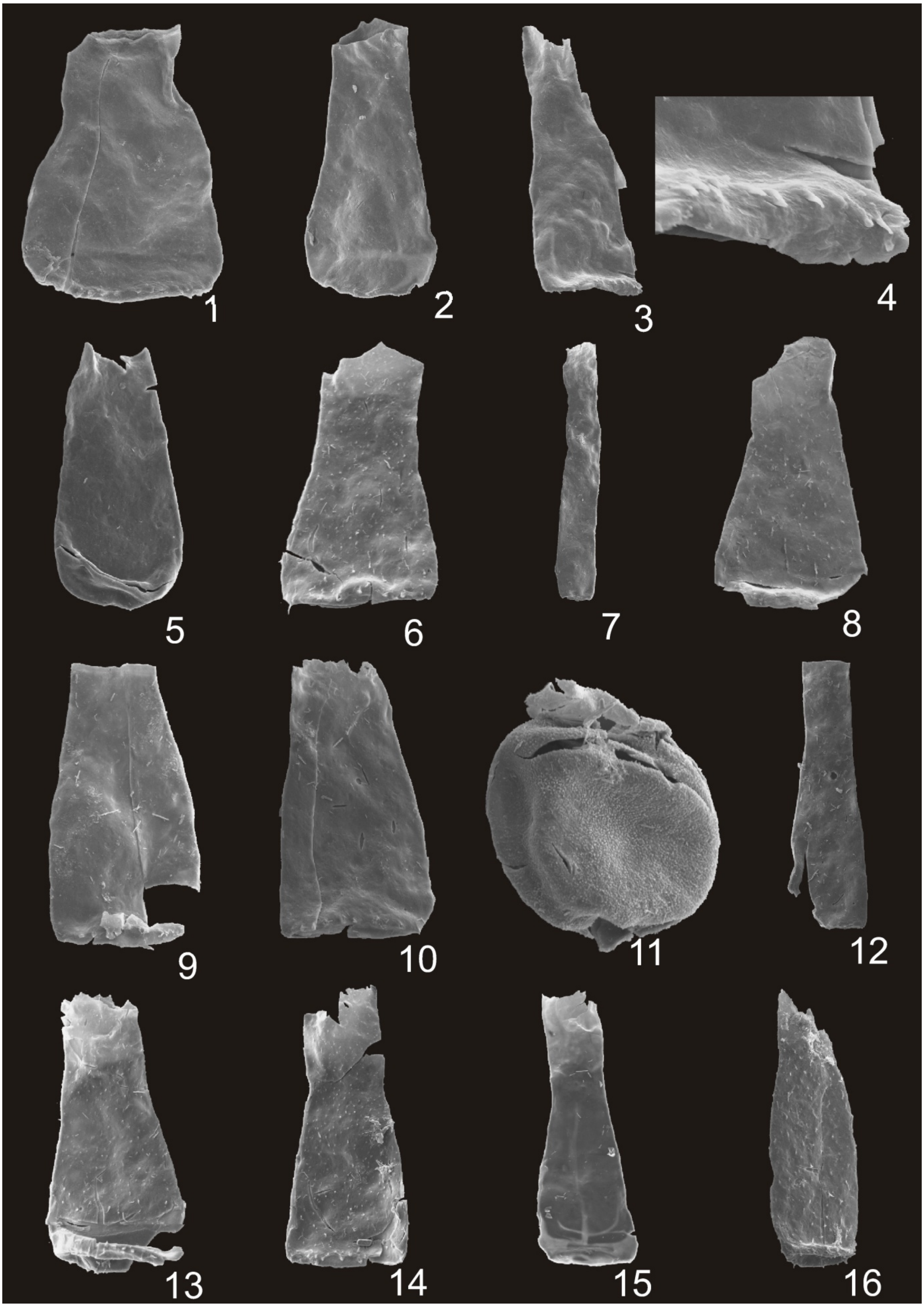


Plate II.2.2.

3. Neuville-sous-Huy, Parc de la Neuville

3.1. Location

Neuville-sous-Huy is a hamlet belonging to municipality of the city of Huy and located approximately 3.5 km to the east of Huy. In the Neuville-sous-Huy area four sections are present: the Parc de la Neuville and three other sections referred by distance to the Parc de la Neuville, the ravine 700 m east of Parc de la Neuville, the ravine 1200 m east of Parc de la Neuville and the new road 300 m west of Parc de la Neuville (see fig. II.3.1). In this chapter we will discuss the section of Parc de la Neuville. The new road 300 m west of Parc de la Neuville will be discussed in chapter II.4, the section ravine 700 m east of Parc de la Neuville will be discussed in chapter II.5, the section ravine 1200 m east of Parc de la Neuville will be discussed in chapter II.6.

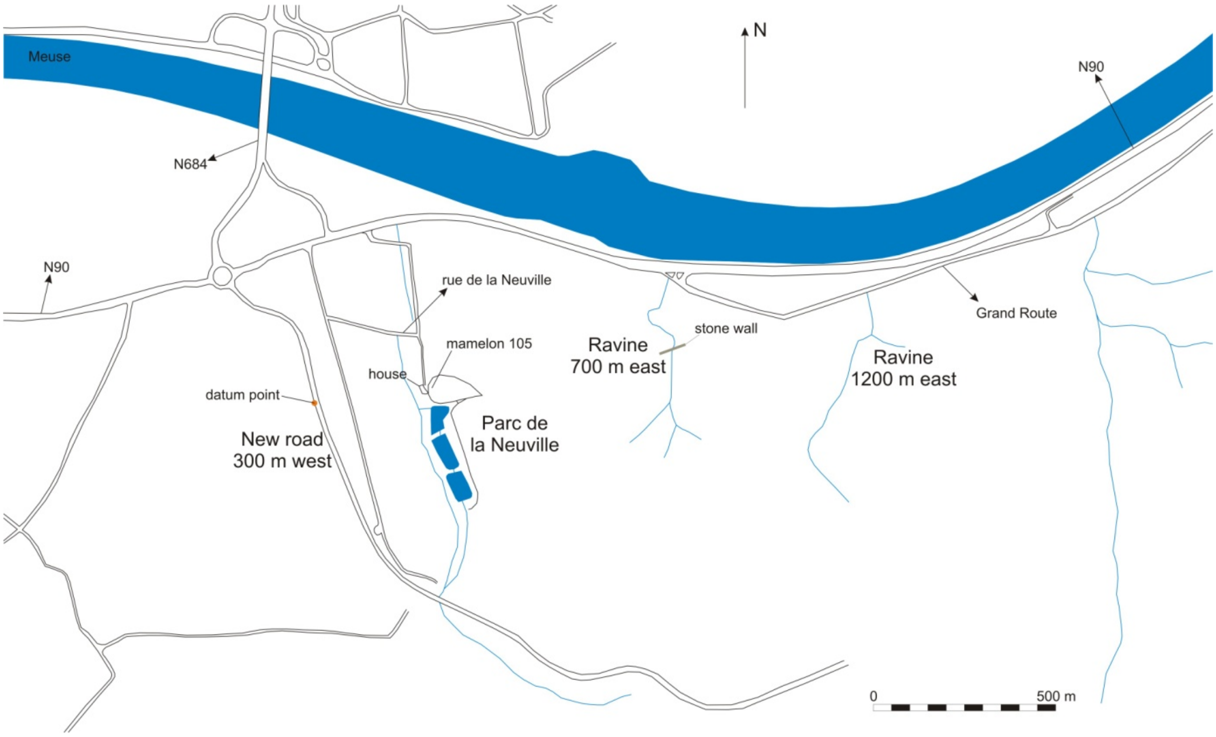


Fig. II.3.1. Map with an overview of the four section of Neuville-sous-Huy.

In the previous domain of the castle of la Neuville, three ponds are orientated NNW. To the east of the ponds and northwards along "mamelon 105" several outcrops occur. The term "mamelon 105" is used for a small hill that is present just northwards of the three ponds and is situated on the topographic line 105 meters. The outcrops are referred to in the literature as Parc de la Neuville and can be divided in a northern and a southern part.

3.1.1. Northern part

We refer to all the outcrops situated north of the southern pond of Parc de la Neuville with the name "northern part of Parc de la Neuville". They are situated along the eastern side of the

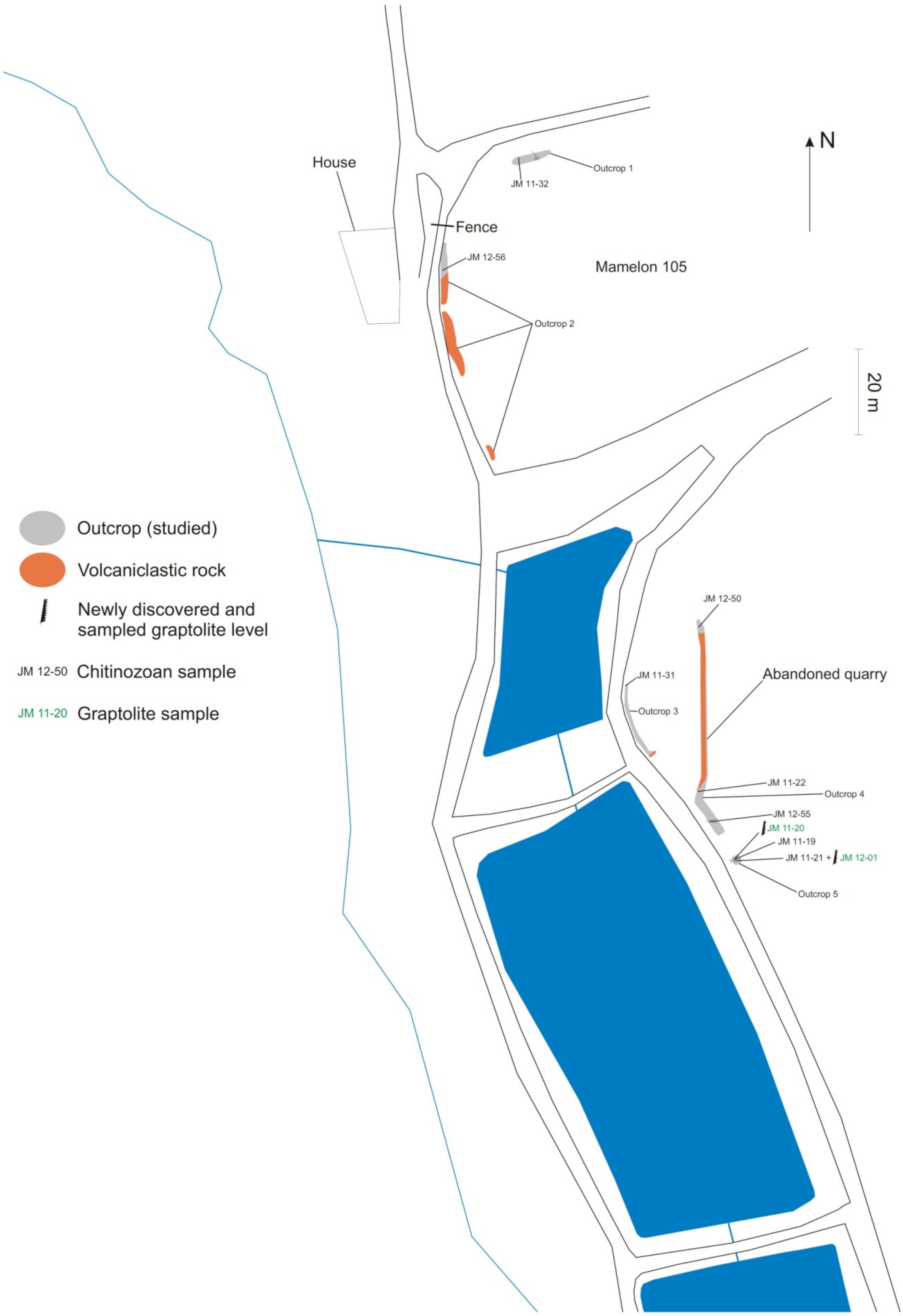


Fig. II.3.2. Map of the section northern part of Parc de la Neuville.

two most northerly ponds, and further along a forest path northwards until just north of a house (see also fig. II.3.2).

In this chapter we will focus on the sedimentary layers. Other authors have studied the volcaniclastic layers but these are mentioned in chapter II.7.

3.1.1.1. Earlier studies

Michot (1932a, 1934) described the layers along the path west of "mamelon 105" from north to south as follows (see also fig II.3.3):

a. Red shale with locally green shale outcropping over a distance of 22.5 meters and a thickness of 15 meters.

b. Green shale dipping 70° to the south and a thickness of 5 meters.

c. "Arkose" with a chloritic cement.

The "arkose" describes a complicated synform with an intermediate antiform where in the axis the green shales of unit b reappear.

The term "arkose" at that time was used with varying definitions. In general it is meant for a coarse grained sandstone with a substantial amount of feldspar.

d. In the southern flank of the fold the "arkose" reappear, dipping 50° to the north. It is followed further southwards by green shale of unit b and next followed by red shale of unit a.

Further southwards along the northerly pond the following units are present going southwards:

e. Red shale of unit a dipping 65° to the south. It is followed by green shale with a thickness of 4 to 5 meters.

f. In a small abandoned quarry facing the most southern side of the northern pond an "arkose" with a chloritic cement is present. The thickness is 3-4 meters. It is coarse grained in the lower part and it becomes finer going upwards. Towards the top some intercalations are present that are mainly sericitic containing some angular grains with a weak diameter.

The abandoned quarry shows weakly south dipping faults with a displacement to the north above the fault (see fig. II.3.4). The reappearance of unit a, b and c along the abandoned quarry (and just north of it) is explained by an antiform between the mamelon 105 and the abandoned quarry.

g. Green shale with sometimes a thin intercalation of red shale and a thin intercalation of sericitic shale indicating the reappearance of the "arkose".

Some meters to the south of the abandoned quarry unit h is found. It contains finely laminated, reddish shale. He correlates the shale with these of the lower Wenlock. He assumes the presence of a fault between unit g and unit h.

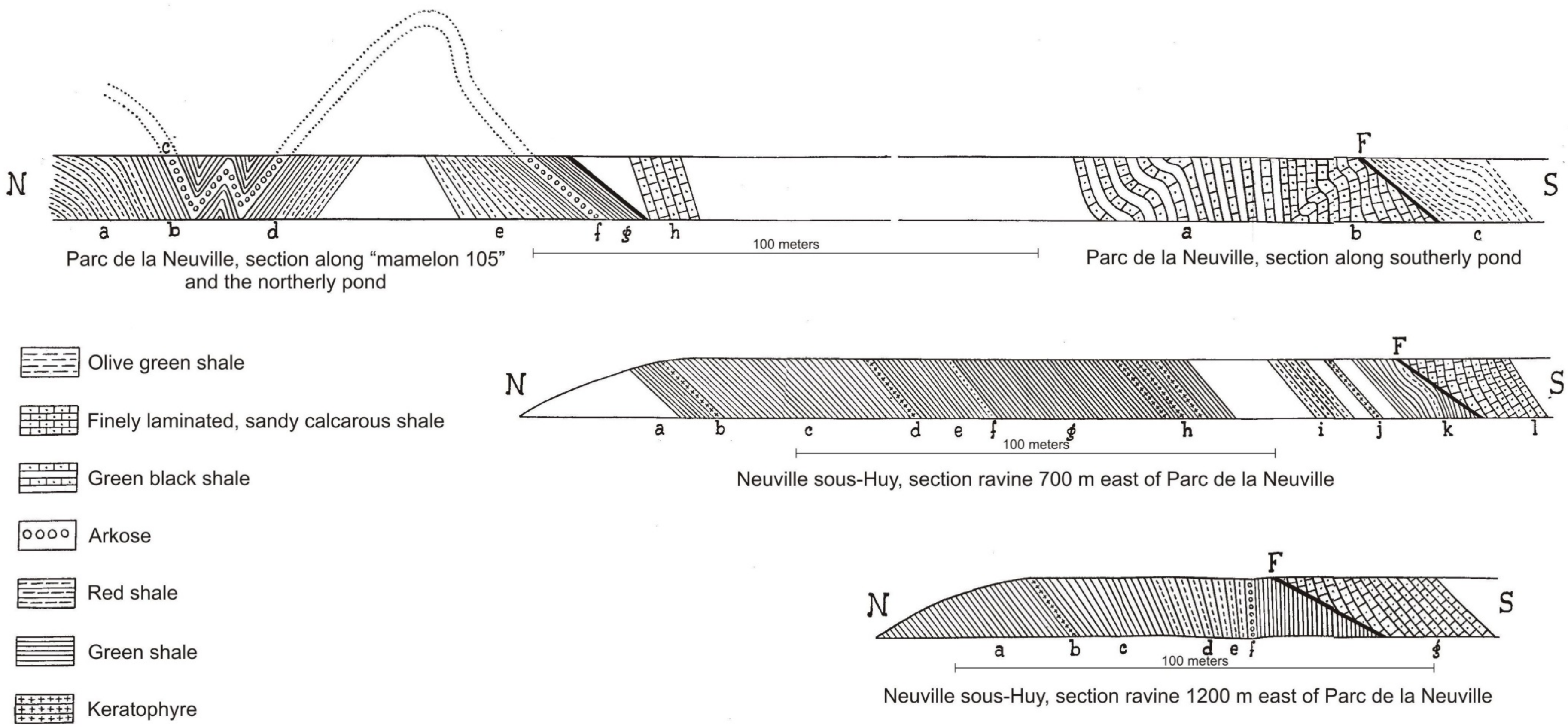


Fig. II.3.3. Sections of Parc de la Neuville, ravine 700 m east of Parc de la Neuville and ravine 1200 m east of Parc de la Neuville according to Michot (1934). Modified from Michot (1934).

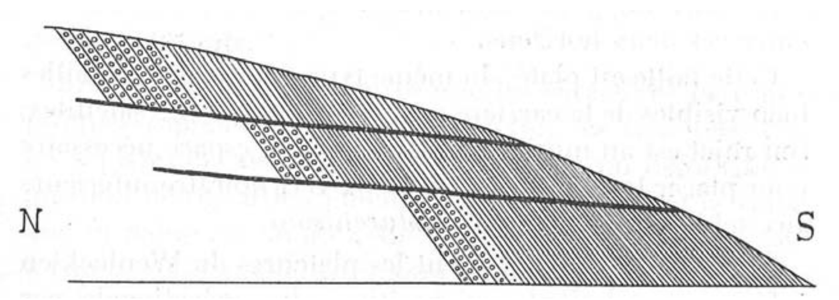


Fig. II.3.4. The abandoned quarry with weakly south dipping faults. Legend see fig. II.3.3. From Michot (1934).

Martin (1966, 1969a) has studied the acritarchs in 14 samples (see fig. II.3.5). She made an inventory and describes the acritarchs present in the units defined by Michot (1934).

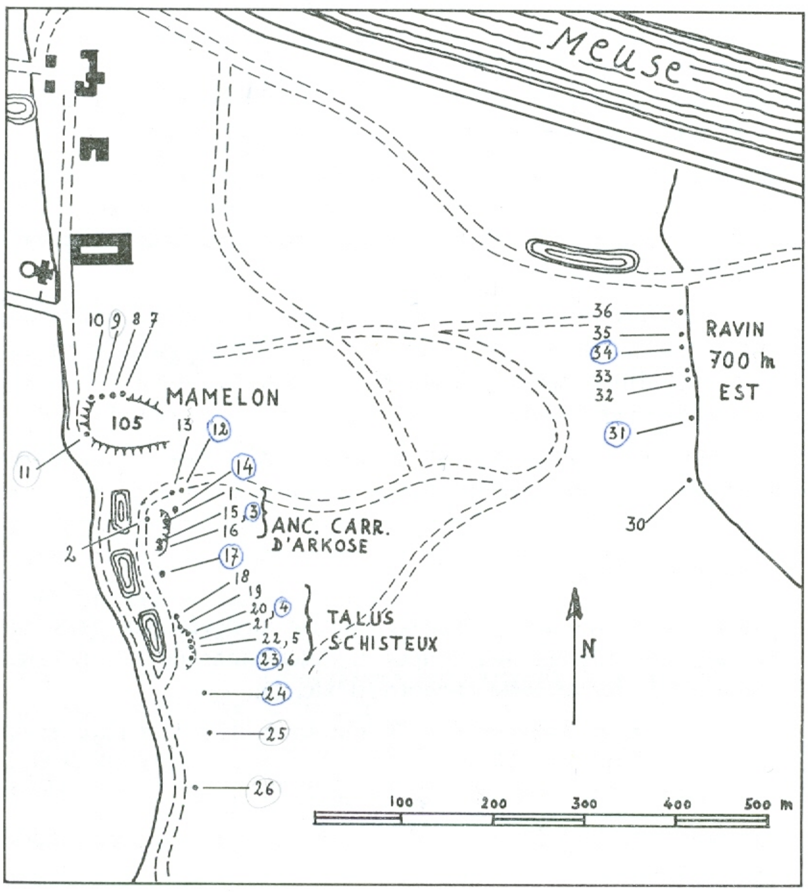


Fig. II.3.5. Overview of the samples that Martin (1966, 1969a) studied. The samples that contain acritarchs are encircled. From Martin (1966).

Van Doorne (1975) did observations along the mamelon 105 and in the neighborhood of the abandoned quarry where Michot (1932a, 1934) has described the “arkose”. Distances are not always accurately given.

He made the following observations going from north to south along the mamelon 105 over a distance of 70 meters (according to his map). In his further observations he does not mention always the distances.
He observed the contact of a tuff with olive green shale. The olive green shale reach a thickness of 3 meters and he considers this as the unit b of Michot (1932a, 1934). Further northwards he observed a centrimetric to decimetric alternation of olive green, brown green, green brown and purple red shale with a total thickness of 6.62 meters. (unit a of Michot, 1932a & 1934). The tuff (unit c of Michot, 1932a & 1934) becomes finer going southwards. In the first 7.7 meters he considers it as a coarse-grained tuff. 13.7 meters southwards of the contact he mentions an impression that the beds are dipping to the north but this is not measurable. He observed this tuff further southwards over a distance of 43.7 meters. In the most southerly outcrop he considers it as a medium-grained tuff.

Along the abandoned quarry, north of it, he made the following observation going from north to south. He observed olive green, millimetrically laminated shale. It is followed by a centimetric to decimetric alternation of olive green and purple red shale with a total thickness of 5.94 m. This alternation is suddenly interrupted by the presence of a tuff. The contact is quite abrupt and not according to the bedding of the rock but subvertical. Hence he assumes the presence of a fault contact between the shale and the tuff. He observed mostly strongly weathered tuff but in between he found 1.6 meters olive green shale. The tuff becomes finer and softer going southwards.
In the abandoned quarry itself a more complex succession has been observed: a coarse-grained tuff that becomes progressively finer going southwards and passing into pale brown, fine-grained shale. The tuff has a minimal thickness of 8 meters and the pale brown shale has a thickness of 1.3 meters. This shale is succeeded southwards by green shale. The coarse grained tuff consists of grains of 3-4 mm of quartz, feldspar and chlorite. The medium-grained tuff can contain softer layers that are less compact and are broken. They contain millimetric to centimetric laminae and are rhythmic. The outcrop contains a two centimeters thick soft layer of kaolinite bearing clay, white-yellow with orange patches. This is considered as fault levels.
Towards the south, outside the excavation, he observed a decimetric alternation of olive green and purple red shales

3.1.1.2. Lithological results

We only made a preliminary study of the outcrops present in the northern part of Parc de la Neuville. More attention have been made on the present volcaniclastic layers. They will be discussed in chapter 7. Below only the sedimentary layers will be described. In most cases thicknesses could not be measured and hence no lithostratigraphical column has been constructed. We have divided the studied outcrops into five different outcrops.

Outcrop 1

The outcrop is situated at the northern to northwestern edge of mamelon 105. It consists of an alternation of red, green, olive green to grey and dark grey mudstone. This outcrop runs further to the east along the northern side of mamelon 105 (see fig. II.3.1).

Outcrop 2

The outcrop is located on the western side of mamelon 105 along a small path. It consists of mainly volcaniclastic rock (see chapter II.7). A fence is present at the northern side of the outcrop. The volcaniclastic layer starts at 12.5 meters south of the fence. The outcrop continues further northwards and passes nearly continuously into outcrop 1. From 4 meters to 12.5 meters south of the fence red, green, olive green to grey and dark grey mudstone occurs. Further northwards until outcrop 1 the same lithology is present. No thickness can be given.

Outcrop 3

The outcrop is located on the eastern side of the path that is running towards the abandoned quarry in southern direction. It runs parallel with the northerly outcrops present in the abandoned quarry but is located lower. It consists of grey to olive green mudstone. Dark purple to black mudstone with beige coloured, flattened, siliceous nodules also occur.

Outcrop 4

The outcrop is situated in the abandoned quarry and just south of it. The abandoned quarry mainly consists of volcaniclastic rock (see chapter II.7). At the northern end of it 60 cm of weathered mudstone occurs, possibly grey-green. It is followed by 60 cm of no outcrop and followed by 200 cm of weathered mudstone, possibly grey-green. The mudstones are interrupted by a volcaniclastic rock. Towards the south of the excavation the volcaniclastic layer disappears and green, olive green to grey-green mudstone do occur. Just south of the excavation red mudstones have also been observed.

Outcrop 5

The outcrop is located 6 meters to the south of the most southerly outcrop of outcrop 4. It consists of dark grey, mainly finely laminated mudstone. This lithology represents laminated hemipelagites. Beds that are compact (grey to dark grey) also occur. The observed thickness is 1.5 meters.

In all the outcrops the bedding is towards the south.

In most of the outcrops (except outcrop 5) faults are present clearly affecting the rocks. But the displacements along most of these faults are centimetric, decimetric to metric and hence of minor importance. Outcrop 4 is an exception. A weakly south dipping fault is present in most of the excavation. Below the fault the volcaniclastic rock is present. Above the fault green, olive green to grey green mudstone do occur. One layer of red mudstone have also been observed above this fault. The displacement along this fault could not be determined.

3.1.1.3. Chitinozoan results

Only one sample has been taken for a chitinozoan study in most of the five outcrops (see table 3.1). The abundances are low (lower than 1 chitinozoan per gram of rock) and the chitinozoans are poorly preserved. Many specimens could only be identified to generic level or as a fragment of an unidentified chitinozoan. Most of the specimens identifieded to species level are in open nomenclature. This low abundance is most probably caused by the weathering of the rocks in most outcrops (except outcrop 5 where the rocks are not so weathered) and the presence of faults.

Outcrop	Sample number	*Eisenackitina causiata*	*Conochitina* spp.	*Ancyrochitina* spp.	*Desmochitina* spp.	*Belonechitina* spp.	*Tanuchitina* spp.	*Margachitina margaritana*	*Eisenackitina causiata?*	*Angochitina longicollis?*	*Angochitina* spp.	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
5	JM 11-21							1	6	7	10	9	33	38.30	0.86
	JM 11-19							1				1	2	37.06	0.05
4	JM 12-55												0	20.21	0.00
	JM 11-22												0	35.97	0.00
	JM 12-50											1	1	21.41	0.05
3	JM 11-31						1					6	7	34.39	0.20
2	JM 12-56		1		1	1							3	21.53	0.14
1	JM 11-32	4	1	5	2							17	29	38.49	0.75
Total		4	2	5	3	1	1	2	6	7	10	34	75	247.36	0.30

Table II.3.1.: Chitinozoan results of Neuville-sous-Huy, northern part of Parc de la Neuville.

In outcrop 1 in sample JM 11-32 *Eisenackitina causiata* is present. From outcrop 2 sample JM 12-56 contains chitinozoans that could only be determined to genus level. The same can be said from sample JM 11-31 from outcrop 3 where only one specimen could be determined to genus level aside of other unidentified chitinozoans. The other specimens just that they are chitinozoans. From outcrop 4 three samples were studied, with two of them barren. The other sample, JM 12-50, contains only one chitinozoan. Outcrop 5 contains samples that are the richest of the entire northern part of Parc de la Neuville. It contains *Margachitina margaritana* next to specimens of taxa in open nomenclature: *Eisenackitina causiata*? and *Angochitina longicollis*?.

Systematic palaeontology of the chitinozoans

Incertae sedis group Chitinozoa Eisenack, 1931

Order Prosomatifera Eisenack, 1972

Family Lagenochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Angochitininae Paris, 1981

Genus *Angochitina* Eisenack, 1931

Angochitina longicollis?

Plate II.3.1., specimens 3, 4

Material: 7 specimens from JM 11-21.

Dimensions: L: >132->192 µm (neck is broken in all specimens); Dp: 66-73-79 µm (n=5); Dc: 28-30-32 µm (n=3).

Description: we refer for the description to Eisenack, 1959 and additional description to Nestor, 1994.

Discussion: No complete specimens recovered (the neck being broken in all cases) and sometimes an almost complete spine is found but often all the spines were broken off, leaving only traces of the spines on the vesicle wall. The specimens are poorly preserved not allowing a definite attribution to this species.

Order Operculatifera Eisenack, 1931

Family Desmochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Eisenackitininae Paris, 1981

Genus *Eisenackitina* Jansonius, 1964 restrict. Paris, 1981

Eisenackitina causiata?

Plate II.3.1., specimens 5, 6

Material: 6 specimens from JM 11-21.

Dimensions: L: ≥89-≥119 µm (all specimens are possibly broken off towards the apertural pole); Dp: 62-72-81 µm (n=5).

Description: we refer for the description to Verniers, 1999.

Discussion: It is not clear if many specimens are broken off at the top. The vesicle wall of all the specimens is deformed, by pyrite growth within the tegument. Hence a questionable attribution to the species.

Discussion on bio- and chronostratigraphy with chitinozoans

Outcrop 1

Sample JM 11-32 contains *Eisenackitina causiata*. This species appears low in the *Eisenackitina dolioliformis* Biozone (lower Telychian) and Verniers (1999) found it to occur until the middle Sheinwoodian. Hence this is also the range that can be given for this sample.

Outcrop 2 + 3 + 4

No specimens could be identified to the species level, not allowing further conclusion.

Outcrop 5

The two samples taken from this outcrop (JM 11-19 and JM 11-21) contain *Margachitina margaritana*. This species ranges on eastern Baltica from the uppermost Telychian until the middle Homerian (Nestor, 2012; also globally until the middle Homerian, Verniers *et al.*, 1995). Although the first appearance of this species is diachronically and probably controlled by environmental factors (Loydell & Nestor, 2005). In the Banwy River section, Wales (Mullins & Loydell, 2001) it appears in the *Cyrtograptus insectus* Biozone (upper Telychian). In the Ventspils D-3 core (Loydell & Nestor, 2005) the species is present in strata of the upper *spiralis* Biozone (upper Telychian). Interesting to note is the presence of *Eisenackitina causiata?* and *Angochitina longicollis*? in sample JM 11-21. The specimens are not sufficiently well preserved to assign them certainly to this species. The range of *Eisenackitina causiata* has been already discussed above. *Angochitina longicollis* is a species that appears globally (Verniers *et al.*, 1995) in the middle Telychian up to the boundary of the lower and middle Sheinwoodian. If *Angochitina longicollis* is really present we can say that this outcrop ranges from the upper Telychian up to boundary of the lower and the middle Sheinwoodian. The possible presence of *Eisenackitina causiata* does not contradict this age assignment.

3.1.1.3. Graptolite results and discussion with the bio- and chronostratigraphy with chitinozoans

Two graptolite levels have been found in outcrop 5: JM 11-20 and JM 12-01. The graptolites are studied and identified by Prof. Dr. Petr Storch (Institute of Geology AS CR, Prague, Czech Republic).

The graptolites could only be determined to genus level. In sample JM 11-20 *Monoclimacis* sp. occurs and in sample JM 12-01 next to this genus *Pristiograptus* sp. and *Monograptus* sp. occur. The graptolites indicate a range of middle Telychian to lower Homerian.

When we group the graptolite and the chitinozoan results together outcrop 5 can be placed from the upper Telychian until the lower Homerian based on our data. The possible presence of *Angochitina longicollis* limit the upper boundary to the lower-middle Sheinwoodian.

Chitinozoan plate

Plate II.3.1. Chitinozoans from Neuville-sous-Huy, section Parc de la Neuville, northern part.

1. *Eisenackitina causiata*. L: 120 µm; Dp: 100 µm; Dc: 64 µm. JM 11-32. Outcrop 1.

2. *Eisenackitina causiata*. L: 132 µm; Dp: 99 µm; Dc: 63 µm. JM 11-32. Outcrop 1.

3. *Angochitina longicollis*?. L: >150 µm; Dp: 75 µm; Dc: ≤29 µm. JM 11-21. Outcrop 5.

4. *Angochitina longicollis*?. L: >159 µm; Dp: 73 µm; Dc: ≤27 µm. JM 11-21. Outcrop 5.

5. *Eisenackitina causiata*?. L: 119 µm; Dp: 62 µm. JM 11-21. Outcrop 5.

6. *Eisenackitina causiata*?. L: 111 µm; Dp: 81 µm. JM 11-21. Outcrop 5.

7. *Margachitina margaritana*. L: 99 µm; Dp: 85 µm. JM 11-19. Outcrop 5.

8. *Margachitina margaritana*. L: 107 µm; Dp: 68 µm. JM 11-21. Outcrop 5.

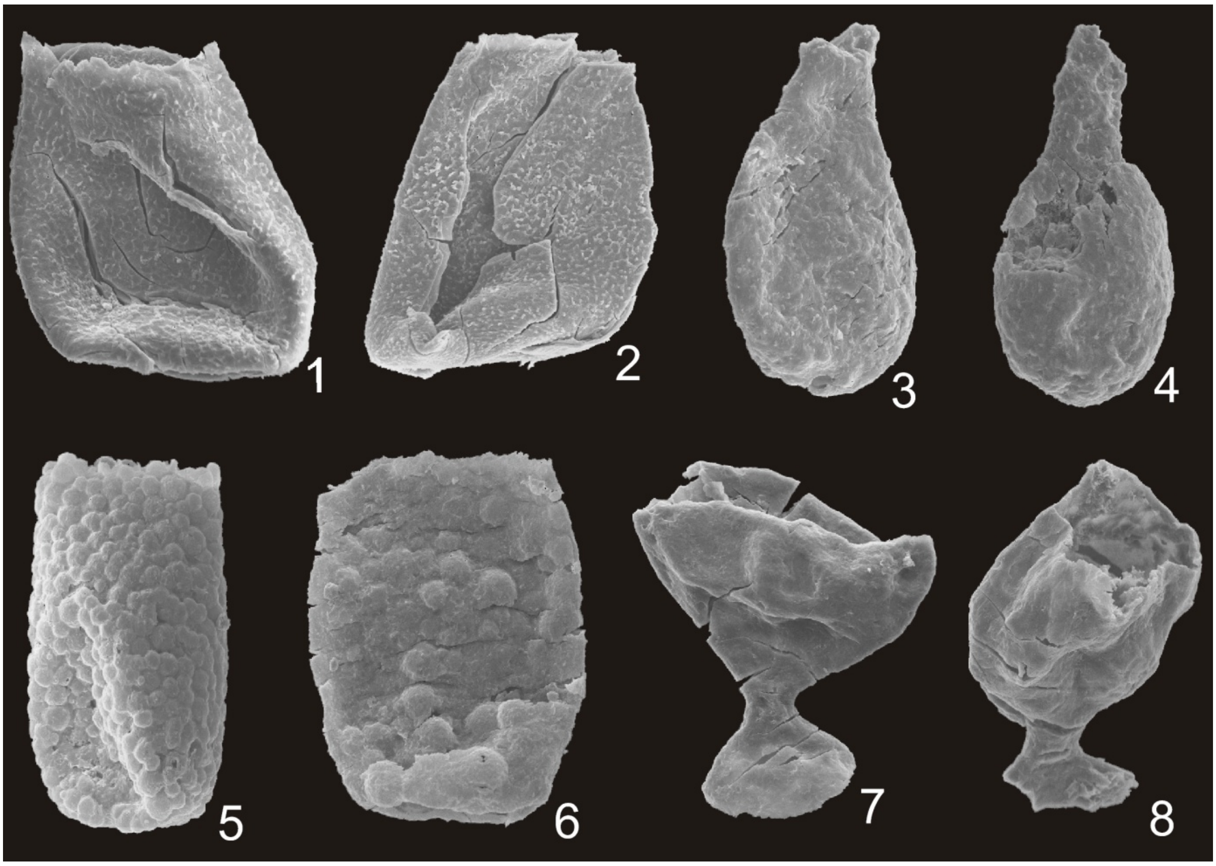


Plate II.3.1.

3.1.2. Southern part

We refer the outcrops situated along the southernmost pond of Parc de la Neuville and south of it with the name “southern part of Parc de la Neuville”. The section is situated on the eastern side of the pond and an outcrop further southwards.

3.1.2.1. Earlier studies

The section along the eastern side of the southernmost pond of Parc de la Neuville has first been studied by Michot (1932a, 1934). He divided the section into four units, from north to south (see fig. II.3.3):
Unit a: green to green black shale with thin, finely laminated intercalations that are finely laminated and a reddish shade. They crop out over a distance of 40 meters and dip 45° to 70° to the south. The observable thickness is approximately 30 meters.
Unit b: sandy, finely laminated shale, slightly calcareous, with locally voluminous limestone nodules. They outcrop over a distance of 20 meters and dip 55° to 75° to the south. The observable thickness is 18 meters. In the northernmost beds the following graptolites have been found: *Cyrtograptus murchisoni*, *Monograptus vomerinus*, *Monograptus dubius* and *Retiolites geinitzianus*. He attributed them to the *Cyrtograptus murchisoni* Biozone, lower Wenlock.
Unit c: green shale of the upper Wenlock separated from unit b by a south dipping fault.
Unit d: approximately fifty meters south of the southernmost pond, bluish coarse grained shale occurs, belonging to the Ordovician.

Martin (1966, 1969a) studied the acritarchs of the section (see fig. II.3.5). She made an inventory and describes the acritarchs present in the units defined by Michot (1934).

Van Doorne (1975), in his Master thesis, compared his observation with these of Michot (1932a, 1934). He describes the following in the same units:
Unit a: alternation of green and black shale locally finely laminated, visible over a distance of 37 m with an average dip of 66° to the south.
Unir b: Olive green, finely laminated shale with an average dip of 52° to the south. In this unit five limestone nodules are present. They are massive with a clear bedding. The bedding of the limestone nodules differs completely from that of the shale.
Unit c: Olive green, finely laminated shale. The fault, mentioned by Michot (1932a, 1934), between unit b and unit c was not observed by him.

Rombouts (1976), in his Master thesis, and the resulting publication in Maes *et al.* (1978), also used the same division as Michot (1932a, 1934), and further divided the units (see fig. II.3.6). From north to south:

Unit a1: olive green, micaceous, nodular shale over a distance of 7 meters. He found microravination in this unit (the northern layers cut through the southern layers, although weakly in the order of 1 mm) and concluded that the unit has been inverted and the beds are younging in northern direction. There are five graptolite levels present, from north to south: α1, γ, α2, β1, β2 (see also table II.3.2.). The level γ contains besides graptolites, also brachiopods, ostracods, crinoids and Conularia. The graptolites in levels α1 and γ allow to place these levels in the *scanicus* Biozone. The levels β1 and β2, and possibly α2 can be located into the *nilssoni* Biozone.

	Pristiograptus dubius	*Bohemograptus bohemicus*	*Saetograptus chimaera*	*Lobograptus scanicus*	*Saetograptus incipiens*	*Monograptus uncinatus*	*Saetograptus varians*	*Monograptus* sp.
α1	X	X	X	X				
γ	X	X	X	s.l. X	X			
α2	X	X	X	?X		?X		
β1	X		X		X		?X	X
β2	X		cf. X					

Table II.3.2.: Identification of the graptolites by B. Rickards of unit a1 in Rombouts (1976).

Unit a2: olive green, micaceous shale over a distance of 24 meters. A bifurcating fault was observed. A weakly ravination of the northerly layers into the southerly layers has been observed. No graptolites found.

Unit b1: grey blue, micaceous, finely laminated shale over a distance of 8 meters. The bedding of the laminae is completely parallel hence the polarity cannot be determined. One graptolite level is present at the end of this unit: δ. It contains *Monograptus flemingii*, Monograptus cf. *flemingii*, *Pristiograptus dubius*, *Cyrtograptus*? *rigidus*. This assemblage allow to place this level into the *rigidus-lundgreni* Biozones.

Unit b2: green, finely laminated shale, weathered to reddish shale, over a distance of 10 meters. To the southern end of this unit three levels with limestone nodules are present. They possess a bedding parallel to the bedding of the surrounding shales. The limestone nodules are probably secondary formed according to him. A microravination of northerly layers into southerly layers has been observed and younging into northerly direction is deduced from this. The presence of clearly bedded laminae, with a wavy pattern of the laminae, indicate an energy-rich environment. Between the lower two levels of limestone nodules a graptolite level is present: ε. It contains *Monograptus flemingii*, *Monograptus* cf. *flemingii*, *Pristiograptus dubius*. This assemblage allow to place this level into the *rigidus-lundgreni* Biozones.

No fault has been observed between unit b and unit c as already mentioned by Van Doorne (1975).

Unit c: olive green, micaceous, nodular shales. A ravination is present of the northern laminae into the southern laminae indicating a younging into northerly direction. No fossils have been found.

Rombouts (1976) observed microravination in unit a1, unit b2 and unit c from southern laminae cut by northern laminae (on the scale of less than 1 cm) and concluded that the entire sequence has been tectonically inverted. The inversion is further supported by the graptolite data showing older graptolite biozones in southern direction.

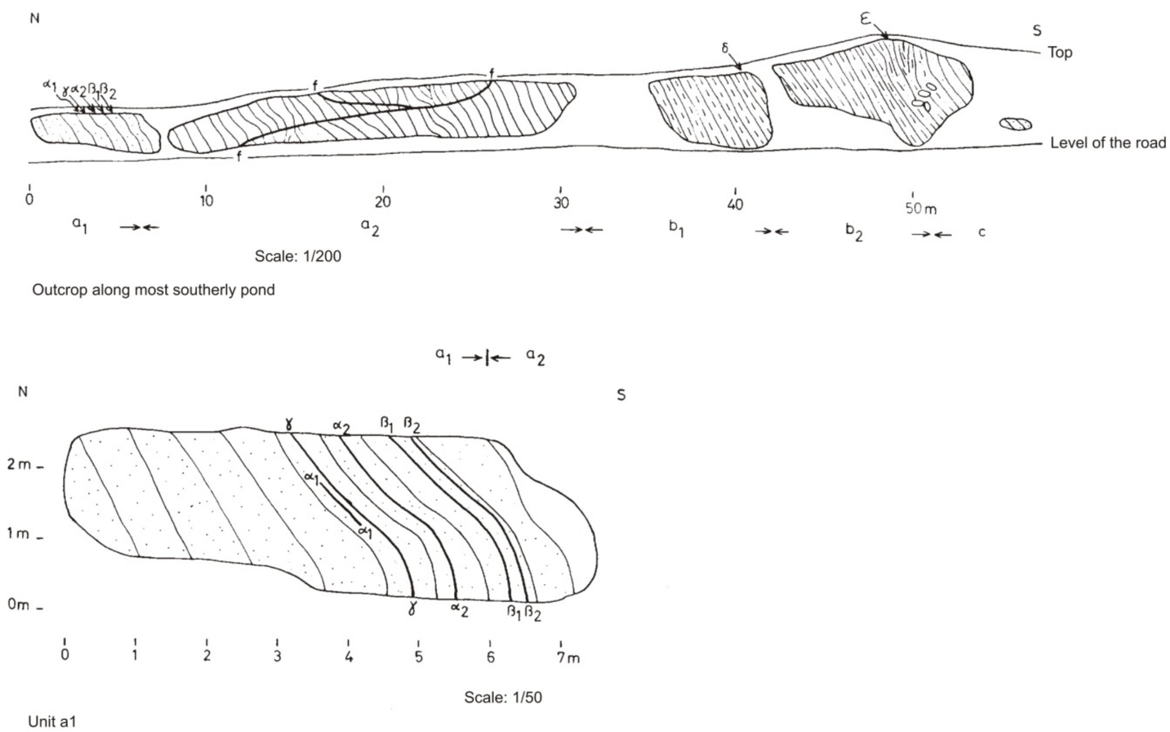


Fig. II.3.6. Section along the most southerly pond of Parc de la Neuville. Modified from Rombouts (1976).

The section is studied by Deckers (2011) during his M.Sc. thesis and reevaluated and restudied during our PhD study. A part of the results are presented at an international conference (Mortier *et al.*, 2012a).

3.1.2.2. Lithological results

After our restudy of the outcrops we agree to use the same units as described and started by Michot (1932a, 1934). In comparison with Rombouts (1976) & Maes *et al.* (1978) refinements have been done in unit a; unit b has been considered as one unit without subdivisions as these subdivisions are probably caused by weathering. The outcrops are present along the eastern path of the southernmost pond starting from 22.8 meters to the south of the dam between the middle and the southern pond, and continuing to the south (see fig. II.3.7 and II.3.8).

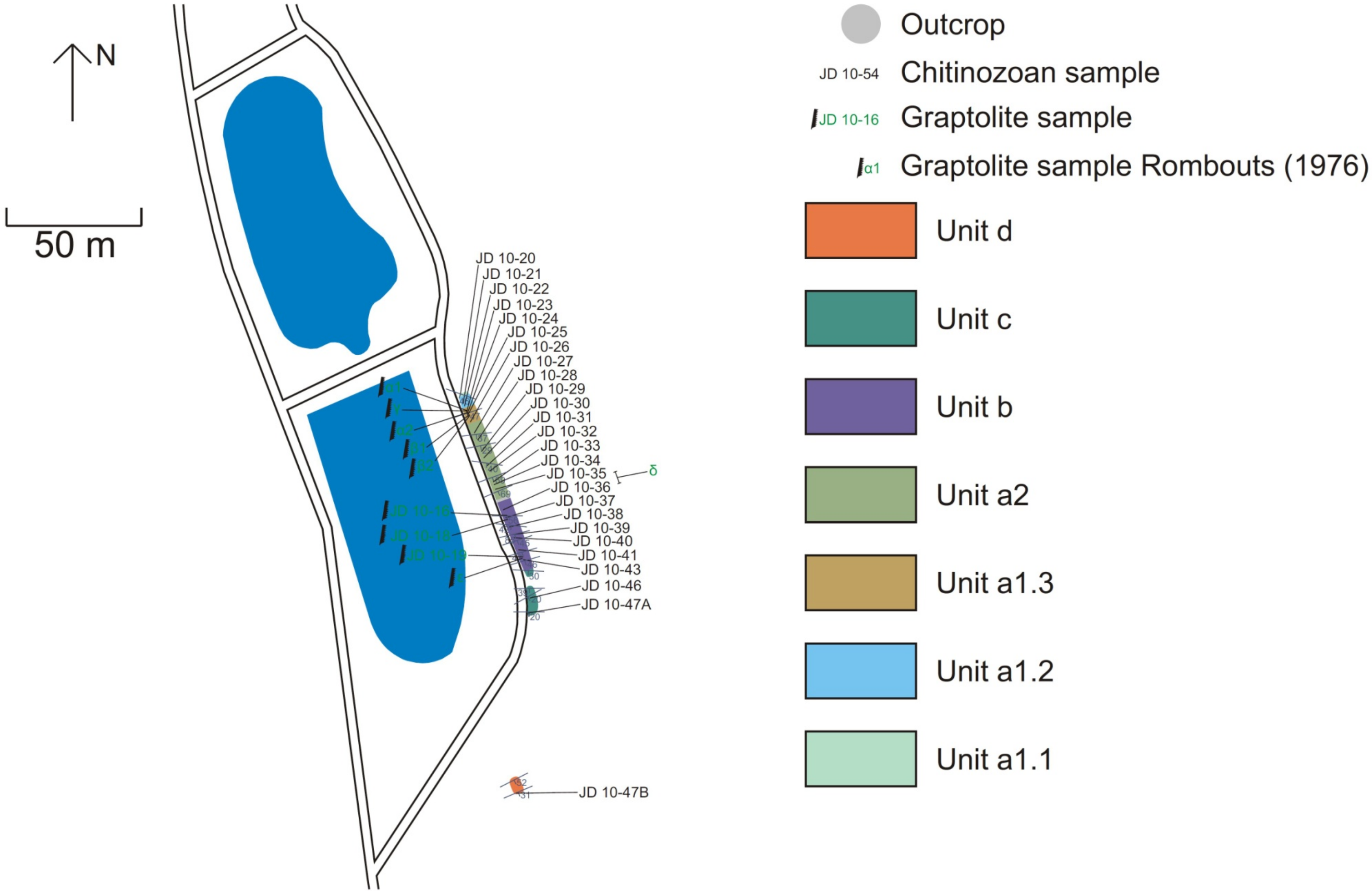


Fig. II.3.7. Map of the section southern part of Parc de la Neuville.

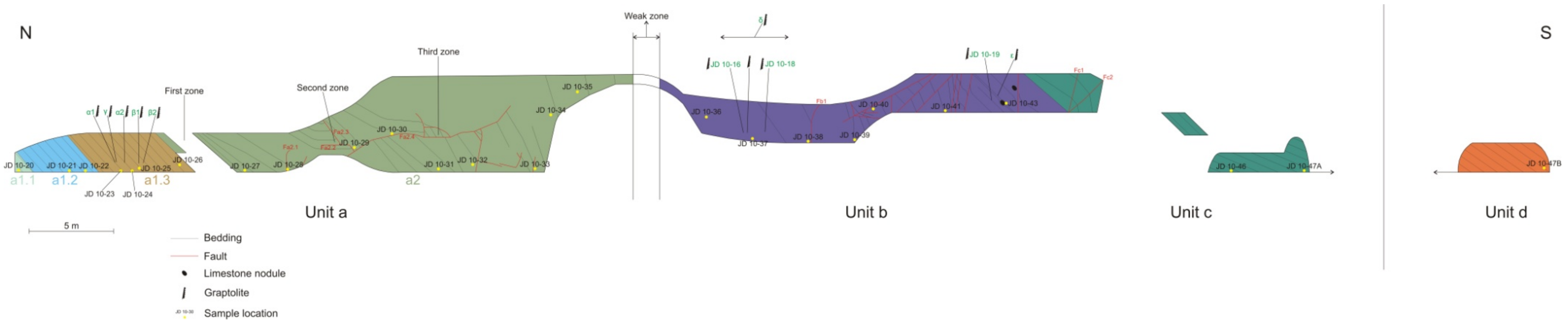


Fig. II.3.8. Section of the southern part of Parc de la Neuville with the location of the chitinozoan and the graptolite samples.

Unit a

Unit a1

A further subdivision into three units is proposed here. The contacts between the different units are all normal stratigraphical contacts. We can propose for the first time thicknesses for each division.

Unit a1.1

Olive green, micaceous mudstone with frequent dark grey to black laminae. This unit is strongly weathered. No macrofossils are present. The main orientation of the beds is Strike 095/Dip 44S and the thickness is 0.8 meters. It crops out over a distance of 1.1 meters. The contact with the covering unit a1.2 is a normal stratigraphical contact.

Unit a1.2

Dark (green-)grey, compact micaceous mudstone with olive green mudstone beds, more prominent close to the boundary with unit a1.1. Most of the olive green mudstone beds are present in the lowest 0.29 meters of this unit. No macrofossils are present. The main orientation of the beds is Strike 082/Dip 45S and the thickness is 3.3 meters. It crops out over a distance of 3.9 meters. The contact with the covering unit a1.3 is a normal stratigraphical contact.

Fig. II.3.9. A pseudo-nodule. Note that the outer layer can be peeled off like an onion.

Fig. II.3.10. Two pseudo-nodules present in the outcrops close to graptolite level α1.

Unit a1.3

Olive green, grey-green to brown-green compact mudstone with beds of dark grey laminated mudstone and brown to rusty-brown laminae. Typical for this unit, and only this unit, is the presence of pseudo-nodules showing an onion like concentric weathering pattern (see fig. II.3.9. and fig. II.3.10.). These pseudo-nodules are more than 1 cm thick and the average length is 5 cm. The core of these pseudo-nodules is compact and grey-green to olive green. The bedding of the surrounding mudstone is bended around these pseudo-nodules. In the laminae of dark grey mudstone five graptolite levels, as described by Rombouts (1976), are present. We give them the same name as in Rombouts (1976): α1, γ, α2, β1, β2. One red mudstone level is present 12 cm below the graptolite level α1 and has a thickness of 4 mm. The main orientation of the beds is Strike 075/Dip 44S and the thickness is 3.5 meters. It crops out over a distance of 5.7 meters. The contact with the covering unit a2 is a normal stratigraphical contact.

Unit a2

Grey to green-grey, compact and laminated, micaceous mudstone. No macrofossils are present. To the south of the unit green grey, less laminated beds are more dominant, in the north the grey beds are more dominant. The thickness is 21 meters. It crops out over a distance of 25.9 meters. The contact between unit a2 and unit b is formed by a very weak zone, possibly a fault. These zone is 1.8 m long.

A lot of faults do occur in unit a2 (see also fig. II.3.7) affecting the bedding. Rusty nodules do occur, along a fault, with the presence of calcite veins in it, a few millimeter thick. Unit a2 is more and more tectonically disturbed and deformed going southwards.

Unit b

Fig. II.3.11. The three limestone nodules present in the outcrop.

Dark grey, finely laminated mudstone with centimetric intercalations of dark grey, compact mudstone. These intercalations of compact mudstone are centimetric to decimetric in thickness. The dominant lithology is dark grey, finely laminated mudstone. The dark grey, finely laminated mudstone are laminated hemipelagites. The rocks are paler at certain places due to weathering. The thickness is 17.9 m. It crops out over a distance of 24.2 meters. Three meters to the north of the boundary with unit c, three limestone nodules do occur (fig. II.3.11). The most northern nodule is 32 cm long and 21 cm thick, the middle nodule is 33 cm long and 7 cm thick (cut in half), the most southern nodule is 35 cm long and 22 cm thick. The mudstones are completely folded around the limestone nodules indicating that the nodules were formed prior to the lithification of the mudstone. The nodules show internally a fine lamination parallel to the bedding of the surrounding rock (fig. II.3.12). The contact between unit b and unit c is a normal stratigraphical contact. Four new graptolite levels have been discovered, besides δ and ε, already mentioned by Rombouts (1976).

Fig. II.3.12. Detail of the middle nodule showing an internally lamination in the nodule.

Unit c

Green-grey to grey, sometimes laminated but also compact, micaceous mudstone. By weathering the rock becomes olive green. No macrofossils are present. The thickness is 4.8 meters. Three zones of outcrops can be distinguished. But they belong all to unit c.

Unit d

Grey-green, micaceous, weathered mudstone. No macrofossils are present. The thickness is 3.6 meters and it crops out over a distance of 5.4 meters. In the northern part of the outcrop the bedding is Strike 067/ Dip 52S, in the southern part the bedding is Strike 071/ Dip 31S.

3.1.2.3. Tectonic deformation

Unit a2 is affected by tectonic deformation (faults) and this becomes stronger going southwards in the unit. This makes it difficult to make a lithostratigraphical column with an exact position of the samples and an exact measurement of the thickness of the unit. These deformations were not or nearly not mentioned by previous authors. Three zones are distinguished and the location of them is indicated on fig. II.3.8.

First zone

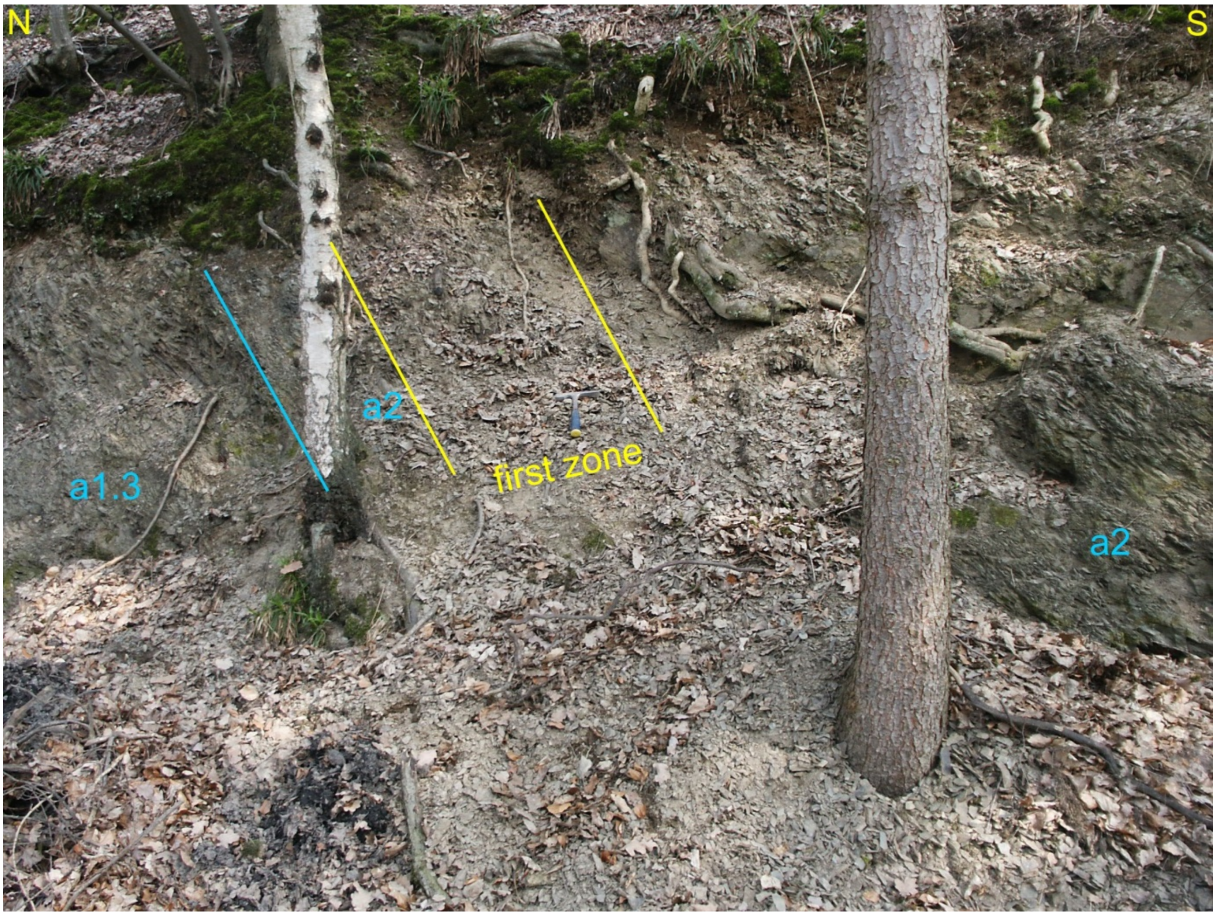


Fig. II.3.13. Location of the first zone in the outcrop.

The first zone (fig. II.3.13) is located 0.7 m southwards of the boundary between unit a1.3 and unit a2 in unit a2. A strongly weathered zone is present here where it is not possibly to determine the lithology. The orientation of the beds cannot be determined caused by strong weathering and the presence of multiple roots. The total length of this zone is 1.8 meters. The thickness present in this zone cannot be determined but is estimated at 1 meter. Possibly faults are present in this zone although they cannot be seen.

Second zone

The second zone is located at the top of the outcrop at 6.5 m and below the outcrop at 7.5 m southwards of the boundary between unit a1.3 and unit a2. Two different structures are here present.

In the first one the layers are dipping to the south (an average of 30°). Going southwards the bedding is curving to the north (steeply). The beds are dipping northwards over a distance of approximately 10 cm and then cut by a fault dipping southwards with 52°. We call this fault Fa2.3. Southwards the beds are steeply dipping to the south (see also fig. II.3.14). We interpret this fault as inverse.

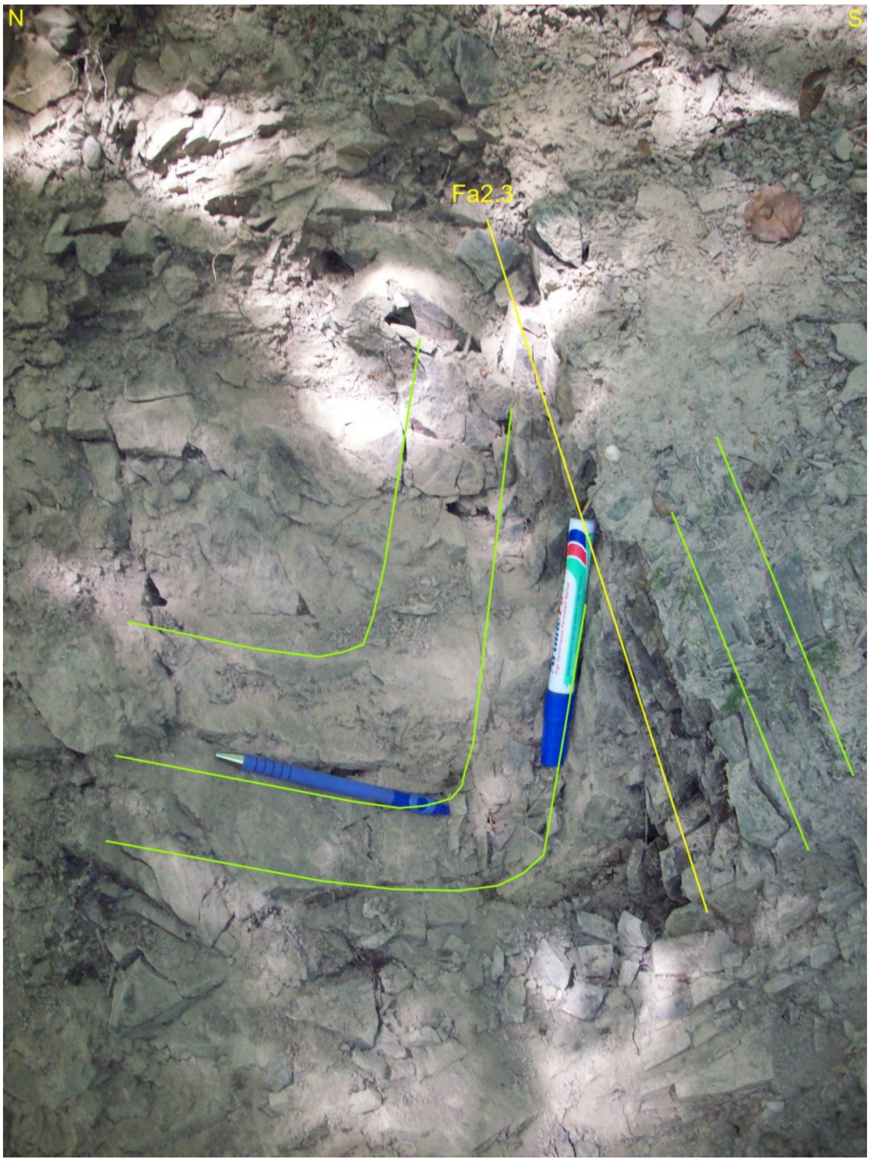


Fig. II.3.14. Outcrop of the first structure in the second zone.

The second disturbance in this zone is caused by a fault Fa2.2 displacing Fa2.3 over a distance of 23 cm. This indicates that Fa2.2 is younger than Fa2.3. Not only Fa2.3 is affected, also the beds around the fault.

Third zone

To the south of the second zone Fa2.4, a mainly north dipping large fault, is present. This is the north dipping fault indicated by Rombouts (1976) in his section of unit a2.. Above this fault the beds are disturbed by less wide and shorter faults. The first 15 m below Fa2.4 is rather undisturbed. The third zone is located by the zone above Fa2.4. The beds above Fa2.4 can be subdivided in zones separated by faults. In these zones the bedding is parallel but they make an angle to other, neighboring zones by faults.

Southwards of fault Fa2.3 and above fault Fa2.4 the beds display, going southwards, a transition of steeply dipping to average dipping and next subhorizontal dipping, always to the south, up against the fault Fa2.4. A subvertical fault, going southwards and almost perpendicular to Fa2.4, stops this phenomenon and south of this the bedding is steepenly dipping.

Fig. II.3.15. Fine rock fragments along fault Fa2.4.

In fault Fa2.4 fine rock fragments are present parallel with the fault (fig. II.3.15). In the first 1.5 m after the start of outcropping of fault Fa2.4 going southwards a zone, with a maximal radius of 30 cm around Fa2.4, compact, lenticular, rusty nodules do occur (fig. II.3.16). They can have a length of more than 10 cm. They are parallel with fault Fa2.4. These nodules are cut by calcite veins of a few millimeters thick. These nodules are also found further southwards in the unit together with other faults.

Fig. II.3.16. On the left a rusty nodule is shown from fault Fa2.4 with a total length of 10 cm. On the right a rusty nodule is present that have been cut open. It shows multiple veins of calcite of different thickness and orientation.

Fig. II.3.17 Previous page. Outcrop of the faulted zone with north unit a2 and south unit b. From base to top in the picture it is 8 meters.

We interpret fault Fa2.4 as a normal fault on the basis of the bedding of the rocks below and above the fault.

At the southern end of unit a2 the beds are becoming in more negative relief going southwards. This has as result that we need to climb higher and also dig deeper to have still rocks present in situ. This becomes more and more present until only a fully faulted zone is present where the rocks are completely broken. The exact lithology of the rocks here cannot be examined together with the bedding. The zone is 1.8 m long. North of it rocks of unit a2 are present, south of it unit b is present. We interpret this zone as a fault zone (fig. II.3.17). The exact position and orientation of the fault cannot be determined.

Fig. II.3.18. Broken zones with in the zones itself a uniformly bedding but differing with neighboring zones. The bedding is indicated with green lines, faults are indicated with yellow lines.

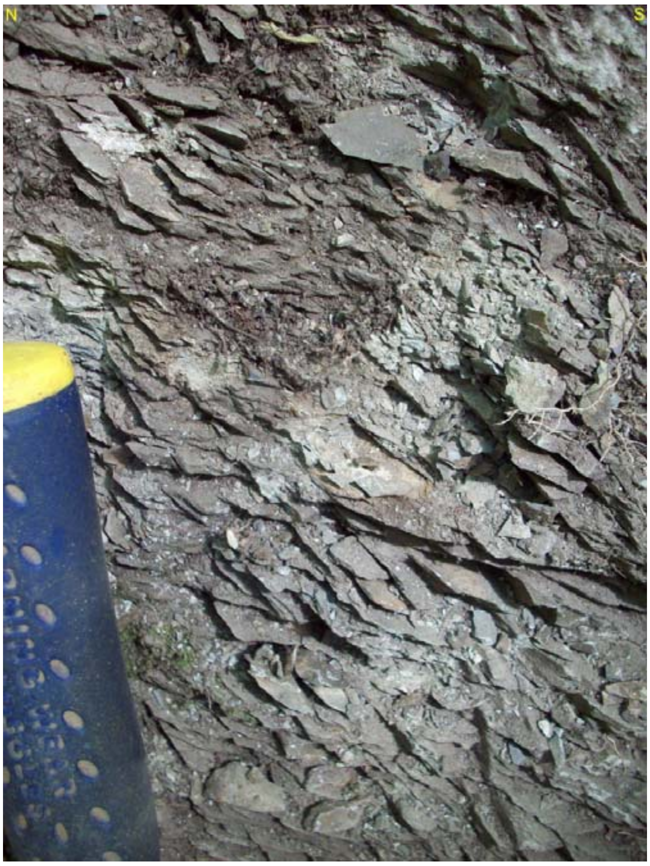


Fig. II.3.19. The rocks are broken into rhomboidal fragments in the most southern outcrop of unit c.

A lot of faults do occur in unit b (see also fig. II.3.8), mostly steeply dipping to the north, and occurring southwards of the fault Fb1. The rocks north of this fault are rather undisturbed.

Southwards of fault Fb1 over a distance of 2.75 m a lot of small faults occur breaking up the section. Southwards of this faulted zone; zones can be distinguished bounded by faults where the bedding is uniformly, but this is different from neighboring zones (fig. II.3.18). This occurs until the boundary with unit c.

The rocks in the most southern outcrop of unit c has been broken into pieces (fig. II.3.19) giving the rocks a rhomboidal like appearance.

3.1.2.4. Chitinozoan results

see also fig. II.3.20.

A total of 670 specimens were obtained from 26 samples (see table II.3.3) of which with 2 were barren (JD 10-39 and JD 10-41). The preservation state of the chitinozoans can vary largely between the different units. Unit a contain moderately well preserved chitinozoans; unit b contain mostly only poorly preserved chitinozoans, with 2 barren samples. Only in sample JD 10-43, from a limestone nodule, the chitinozoans are moderately well preserved; unit c and d yield poorly to moderately well preserved chitinozoans. The abundance of the chitinozoans is generally lower than 1 chitinozoan per gram of rock except for five samples in unit a with a maximum of 2.23 chitinozoans per gram of rock.

Unit a

In the lowermost part of the unit the following chitinozoans do occur: *Conochitina tuba*, *C. rudda*, *C. pachycephala*, *C. claviformis*, *Eisenackitina toddingensis*, *Sphaerochitina dubia* and *Cingulochitina gorstyensis*. They range almost through the top of unit a except for *Eisenackitina toddingensis* to JD 10-32, *Conochitina tuba* to JD 10-28 and *Cingulochitina gorstyensis* to JD 10-27. From sample JD 10-24 onwards *Belonechitina lauensis* is present. A little bit higher in the unit *Salopochitina* sp. 1 is present from JD 10-28 and *Conochitina* cf. *pachycephala* from JD 10-29. Some chitinozoa are only found in one or two samples: *Eisenackitina* cf. *pregranosa* (JD 10-22), *Cingulochitina*? sp. 1 (JD 10-23, JD 10-28), *Angochitina milleri* (JD 10-23, JD 10-24), *Conochitina pumilio* (JD 10-26), *Cingulochitina* sp. 2 (JD 10-26) and *Sphaerochitina* sp. 1 (JD 10-32, JD 10-33).

Unit b

From samples JD 10-36 to JD 10-40 we could identify *Conochitina claviformis*. In sample JD 10-43 *Conochitina* aff. *tuba* and *Conochitina* cf. *gutta* are identified.

Unit c

Only identifications to the genus level were possible, with the most specimens belonging to the genus *Ancyrochitina*.

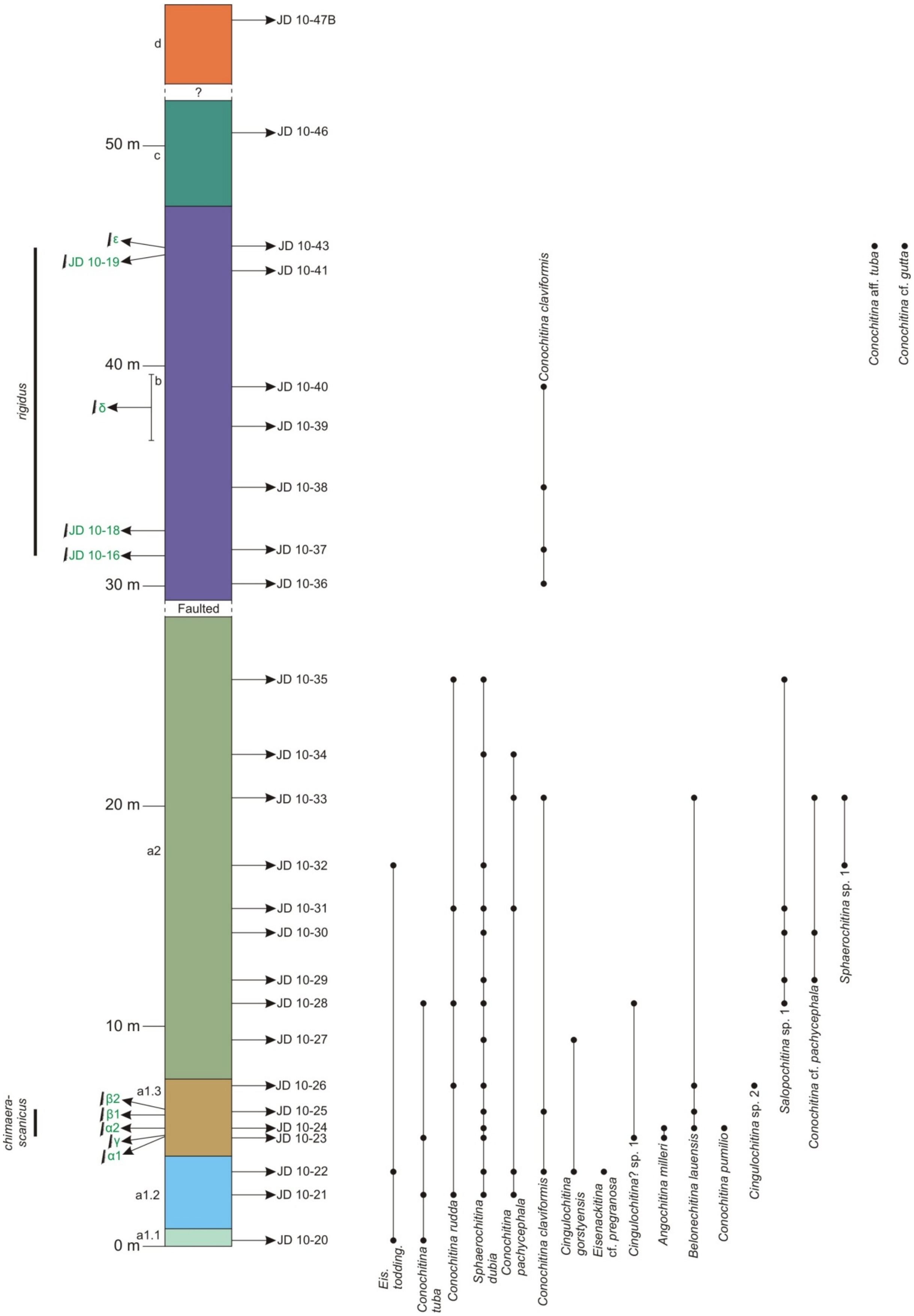


Fig. II.3.20. Litholog of the section Neuville-sous-Huy, southern part of Parc de la Neuville with the distribution of the chitinozoans throughout the section together with the graptolite biozonation.

Unit			Sample number	*Desmochitina* spp.	*Belonechitina* spp.	*Ancyrochitina* spp.	*Eisenackitina toddingensis*	*Conochitina tuba*	*Angochitina* spp.	*Conochitina rudda*	*Sphaerochitina* spp.	*Sphaerochitina dubia*	*Conochitina pachycephala*	*Eisenackitina* spp.	*Conochitina* spp.	*Conochitina claviformis*	*Cingulochitina gorstyensis*	*Bursachitina* spp.	*Salopochitina* spp.	*Cingulochitina*? sp. 1	*Angochitina milleri*	*Belonechitina lauensis*	*Conochitina pumilio*	*Ramochitina* spp.	*Cingulochitina* sp. 2	*Cingulochitina* spp.	*Salopochitina* sp. 1	*Fungochitina* sp.	*Conochitina* cf. *pachycephala*	*Sphaerochitina* sp. 1	*Calpichitina* spp.	*Conochitina* aff. *tuba*	*Conochitina* cf. *gutta*	*Cyathochitina* spp.	*Spinachitina* spp.	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
d			JD 10-47B			4								2	6			3																1	1	11	28	35.73	0.78
c			JD 10-47A			3		1			2			1	4																					4	15	37.25	0.40
			JD 10-46		1	9					1													1												5	17	37.77	0.45
b			JD 10-43			1					2																					16	1			1	21	35.85	0.59
			JD 10-41																																		0	36.29	0.00
			JD 10-40			1									5	3																				4	13	36.99	0.35
			JD 10-39																																		0	35.72	0.00
			JD 10-38												10	1																				19	30	36.85	0.81
			JD 10-37			2									8	1		1																		7	19	35.44	0.54
			JD 10-36			1										1																				1	3	35.22	0.09
a	a2		JD 10-35		1	16				1		1		2	6												1	1			3					13	45	36.60	1.23
			JD 10-34			3			1			1	3	1	4																					6	19	36.01	0.53
			JD 10-33		4	6							1	4	7	2		1				2				1			2	1						18	49	36.24	1.35
			JD 10-32		1	8	1		1			1			2			1						1						1						9	26	36.43	0.71
			JD 10-31		1	17				1		1	2	2	4									2			2									17	49	37.55	1.30
			JD 10-30		1	8					1	3						2						1			2		1							17	36	38.04	0.95
			JD 10-29		1	7					1	2			4									2			1		2							10	30	35.31	0.85
			JD 10-28		1	3		1		2		2		2	2					1						1	1	1								9	26	36.87	0.71
			JD 10-27		1	6						1		2	2		1	3								1										5	22	36.80	0.60
	a1	a1.3	JD 10-26	1	1	15			2	1		1		1	3							2			4											7	38	36.57	1.04
			JD 10-25			5						1				1						2		1												1	11	35.08	0.31
			JD 10-24			50					6	4			6			2			1	1	2													9	81	36.31	2.23
			JD 10-23			8		1	1		3	2								1	1															4	21	35.60	0.59
		a1.2	JD 10-22		3	10	3				3	1	1	3	4	1	1	1	1																	3	35	35.46	0.99
			JD 10-21			6		2	1	3	4	1	1	1																						5	24	36.03	0.67

		a 1.1	JD 10-20	2	1	4	1	2																												2	12	36.77	0.33
Total				3	17	193	5	7	6	8	23	22	8	21	77	10	2	14	1	2	2	7	2	8	4	3	7	2	5	2		16	1	1	1	187	667	944.78	0.71

Table II.3.3. Chitinozoan results of Neuville-sous-Huy, southern part of Parc de la Neuville.

Unit d

Specimens could be identified only to the genus level: *Ancyrochitina* spp., *Eisenackitina* spp., *Conochitina* spp., *Bursachitina* spp., one *Spinachitina* sp. and one *Cyathochitina* sp. The specimen of *Spinachitina* sp. and *Cyathochitina* sp. are both poorly preserved and are possibly reworked.

Systematics of the chitinozoans

Incertae sedis group Chitinozoa Eisenack, 1931

Order Prosomatifera Eisenack, 1972

Family Conochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Conochitinae Paris, 1981

Genus *Conochitina* Eisenack, 1931 emend. Paris *et al.*, 1999

Conochitina cf. *gutta*

Plate II.3.5., specimen 9

Material: 1 specimen from JD 10-43; unit b.

Dimensions: based on 1 flattened specimen with broken neck; L: 144 µm; Dp: 81 µm; Dc: 55 µm.

Description: we refer for the description to Laufeld (1974).

Discussion: The only feature that this specimen distinguish from *Conochitina gutta* is that the chamber is cylindrical and not conical. It can be confused with *Eisenackitina lagena* (Eisenack, 1968) although it is a bit bigger and the ornamentation is also different (spongy and not rugose ornamentation).

Conochitina cf. *pachycephala*

Plate II.3.2., specimens 13-15

Material: 2 specimens from JD 10-29, 1 specimen from JD 10-30, 2 specimens from JD 10-33; unit a2.

Dimensions: due to the broken nature of all the specimens, it is not possible to give dimensions.

Description: we refer for the description to Eisenack, 1964 and additional description to Nestor, 1994.

Discussion: Only specimens with a constriction of the vesicle just oralward of the basal edge have been identified as *Conochitina pachycephala*. The specimens identified as *Conochitina* cf. *pachycephala* lack this distinguishing feature. Next to this parameter the mucron is not seen on the specimens although this can be broken off in some specimens. Hence the use of open nomenclature.

Conochitina aff. *tuba*

Plate II.3.5., specimens 4-8

Material: 16 specimens from JD 10-43; unit b.

Dimensions: L: 180-188 µm (n=2); Dp: 59-69-78 µm (n=12); Dc: 43-50 µm (n=2).

Description: we refer for the description to Eisenack, 1932 and Nestor, 1994; discussion in Laufeld, 1974. They are all characterized by a rugose ornamentation forming little spines, but these are never large enough to include the specimens into the genus *Belonechitina*. The ornamention is less developed at the oral margin.

Discussion: This species dominates in sample JD 10-43. The specimens are almost always broken but easily recognizable. The ornamentation distinguish the specimens from typical specimens of *Conochitina tuba* that has never ornamentation. The broken nature of many (almost all the) specimens hamper the formation a new species and to know the total length of the specimens. It can be distinguished from the following species: *Conochitina cribosa* (Nestor, 1982a & 1994) has almost never a clear protruding mucron and the ornamentation is too developed; *Conochitina fortis* (Nestor, 1982a & 1994) is subcylindrical and has never an ornamentation; *Conochitina gutta* (Laufeld, 1974) has the form of a droplet; *Conochitina visbyensis* (Laufeld, 1974) is smaller and has a smaller mucron; *Belonechitina postrobusta* (Nestor, 1980b & 1994) has thicker spines and has never a protruding mucron.

Family Lagenochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Lagenochitininae Paris, 1981

Genus *Sphaerochitina* Eisenack, 1955a emend. Paris *et al.*, 1999

Sphaerochitina sp. 1

Plate II.3.4., specimen 10

Material:1 specimen from JD 10-32, 1 specimen from JD 10-33, unit a2.

Dimensions: L: 141-152 µm (n=2); Dp:69-71 µm (n=2); Dc: 27-32 µm (n=2).

Description: The vesicle has a long neck passing into a chamber with an unclear flexure and shoulders. The neck is longer than the chamber. The chamber is convex and has a convex base with a broadly rounded basal edge. The neck widens lightly to the apertural pole. The vesicle is covered with small unclear spines that never reach a length to include the specimens in a spiny form of chitinozoan. The ornamentation is slightly bit bigger at the base of the chamber and decreases in size towards the oral part of the vesicle.

Discussion: The only species that approaches our specimens is *Sphaerochitina indecora* (Nestor, 1982b). But the neck is longer in our two specimens and the spines are shorter and less prominent.

Order Operculatifera Eisenack, 1931

Family Desmochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Pterochitininae Paris, 1981

Genus *Cingulochitina* Paris, 1981

Cingulochitina? sp. 1

Plate II.3.4., specimen 6

Material: 1 specimen from JD 10-23, unit a1.3; 1 specimen from JD 10-28, unit a2.

Dimensions: L: 140-144 µm (n=2); Dp: 94-107 µm (n=2); Dc: 58 µm (n=1).

Description: The species has a clear convex chamber with a rounded basal margin. The base itself is concave but carries a large, convex copula. The chamber reaches his maximal width approximately halfway up the chamber. The vesicle is covered with little granules. The carina is short and bears possible processes.

Discussion: The species resembles *Cingulochitina gorstyensis* (Sutherland, 1994). But our specimens are larger, have an ornamentation (although visible on plate 5, picture 7 of Sutherland, 1994), a large copula and a concave base. The chamber of our specimens never reaches so quickly its maximal width going to the aperture. A question mark has been placed next to the genus because possible processes are present but are broken off. When these are present this species needs to be transferred to the genus *Salopochitina*.

Cingulochitina sp. 2

Plate II.3.4., specimens 3, 4

Material: 4 specimens from JD 10-26; unit a1.3.

Dimensions: L: 85-89-94 µm (n=3); Dp: 60-62-63 µm (n=4); Dc: 40-42-44 µm (n=3).

Description: The maximal width of the chamber is quickly reached going to the apertural pole and is not so much bigger as the width of the base. The flanks of the chamber are slightly convex. The species narrows going to the neck and keeps narrowing there. It ends with a large collarette. The flexure and the shoulders are inconspicuous. At the base the species wears a short carina.

Discussion: This species is comparable with *Cingulochitina crassa* (Nestor, 1994). The differentiation between the neck and the chamber is larger in *Cingulochitina crassa* than our species. The flanks of the chamber are less convex in our specimens.

Subfamily Orbichitininae Achab, Asseling & Soufiane, 1993

Genus *Salopochitina* Swire, 1990 emend. Paris *et al.*, 1999

Salopochitina sp. 1

Plate II.3.4., specimens 7-9

Material: 1 specimen from JD 10-29, 2 specimens from JD 10-30, 2 specimens from JD 10-31, 1 specimen from JD 10-35, unit a2.

Dimensions: L: 91-128-170 µm (n=6); Dp: 79-88-94 µm (n=3); Dc: 42-44-47 µm (n=3).

Description: The vesicle has a rounded basal edge. The maximal width of the chamber is quite quickly reached; starting from the base going to the aperture, and the value is not so much higher in comparison with these of the base. The flexure and the shoulders cannot be easily discriminated. The chamber shows a curvature. The vesicle is ornamented with granules (weathered on some specimens). No mucron was observed. Traces of broken processes are observed.

Discussion: The presence of traces of broken processes justifies the assignment into the genus *Salopochitina* and it is easy to confuse with the genus *Eisenackitina*. The specimens show affinities with *Eisenackitina philipi* (Laufeld, 1974) but in our specimens no neck is present (or only a short one) and traces of broken processes are present. The chamber has the same outline as these from *Eisenackitina philipi* and also the dimensions of the chamber fit in the definition of it. The ornamentation is the same but we have never observed a mucron. *Eisenackitina lagenomorpha* (Eisenack, 1931) is different from this species in the form of the chamber and possessing no processes. *Eisenackitina lagenomorpha* has flanks of the chamber that are straight narrowing towards the aperture after reaching the maximal width whilst our specimens show always a curvature in the flanks of the chamber (it is never straight).

Discussion on bio- and chronostratigraphy with chitinozoans

The assemblages of the chitinozoans are different from every unit. Hence we will discuss their occurrences according the units.

Unit a

A first assemblage of chitinozoans do occur in unit a. The following occurring taxa are all longer ranging: *Conochitina pachycephala*, *Conochitina tuba* and *Conochitina claviformis*. They have their highest appearance in the lower to middle part of the *Angochitina elongata* Biozone, upper Gorstian (Sutherland, 1994 & Nestor, 2007, 2009, 2012), as is the same for *Conochitina rudda*. Two other stratigraphically important chitinozoans, *Eisenackitina toddingensis* and *Belonechitina lauensis* start both in the lower part of the *Ancyrochitina desmea* Biozone (Nestor, 2007, 2009). When we join these ranges we can conclude that unit a ranges from the Baltoscandian *Ancyrochitina desmea* Biozone to the lower part of the Baltoscandian *Angochitina elongata* Biozone. According to Nestor (2007, 2009, 2012) this corresponds to the middle Gorstian and lower part of the upper Gorstian.

Unit b

Unit b contains *Conochitina claviformis* (Eisenack, 1931) together with two species in open nomenclature: *Conochitina* aff. *tuba* and *Conochitina* cf. *gutta*. *Conochitina claviformis* is a long ranging chitinozoan ranging from the lower Sheinwoodian to the upper Gorstian in Baltica (Nestor, 2012). We can conclude that the chitinozoans indicate an age of lower Sheinwoodian to the upper Gorstian.

Unit c

One specimen of *Conochitina tuba* (Eisenack, 1932) is present and no other species were found in unit c. It is long ranging in Baltica from the middle Sheinwoodian to the upper Gorstian (Nestor, 2012).

Unit d

In unit d *Spinachitina* sp. occurs. It indicates a range of Upper Ordovician to Llandovery (Paris *et al.*, 1999). When we take this result in account unit d has an age spanning from the Upper Ordovician up to the Llandovery. But the specimen is badly preserved and possibly reworked. Hence the chitinozoans provide no conclusive information on the dating of unit d.

3.1.2.5. Graptolite results

Graptolites occur in unit a1.3 and unit b. The graptolites from unit a1.3 were all collected by us and occur in the five levels described by Rombouts (1976). The graptolites from unit b contain these collected by Rombouts, 1976 (level δ and ε) next to newly collected graptolites by us (three levels). The graptolites are studied and identified by Prof. Dr. Petr Storch (Institute of Geology AS CR, Prague, Czech Republic). The results of the identifications and the resulting biozonation is given in table II.3.4.

The graptolite levels that occur in unit a1.3 belong to the *Saetograptus chimaera-Lobograptus scanicus* Biozone of the middle Gorstian. The graptolite levels that occur in unit b belong to the *Cyrtograptus rigidus* Biozone of the upper Sheinwoodian.

Unit	Graptolite level / sample number	*Pristiograptus* spp.	*Saetograptus* spp.	*Lobograptus* spp.	*Lobograptus scanicus*	*Saetograptus chimaera*	*Pristiograptus dubius frequens*	*Bohemograptus bohemicus*	*Pristiograptus dubius*	*Monoclimacis* spp.	*Cyrtograptus rigidus*	*Plectograptus textor*	*Plectograptus praemacilentus*	*Monograptus flemingii*	*Monograptus* ex gr. *priodon*	graptolite indet.	bivalve	crinoid columnals	nautiloid fragments	Graptolite biozonation
b	ε								X					cf.						*rigidus*
	JD 10-19									X					X					
	δ													aff.						
	JD 10-18	X								X	X					X				
	JD 10-16	X								X	?	aff.	aff.							
a1,3	β2				X		?		X	X						X				*chimaera-scanicus*
	β1	X	X			X	cf.										X	X	X	
	α2	X	X				X	X												
	γ	X			X	X	X									X				
	α1	X	X	?																

Table II.3.4. Graptolite results of Neuville-sous-Huy, southern part of Parc de la Neuville.

3.1.2.6. Discussion

The occurrence of graptolites of the *Saetograptus chimaera-Lobograptus scanicus* Biozone in unit a1.3 confirms the chitinozoan data placing unit a in the Baltoscandian *Ancyrochitina desmea* Biozone to the lower part of the Baltoscandian *Angochitina elongata* Biozone (Nestor, 2007, 2009, 2012) of the middle Gorstian to lower part of the upper Gorstian.

Graptolites in unit b belong to the *Cyrtograptus rigidus* Biozone of the upper Sheinwoodian. They have been found in the lower and in the upper part of unit b indicating the *Cyrtograptus rigidus* biozone. Hence we correlate unit b with the *Cyrtograptus rigidus* Biozone of the upper Sheinwoodian. Chitinozoans that occur in this unit are longer ranging. Noteworthy is the presence of many specimens of *Conochitina* aff. *tuba* in the limestone nodules present in unit b.

Not so much information about the age of units c and d can be given due to the lack of polarity indicators, no graptolite information is present and the chitinozoan data is unsufficient. Only for unit c the chitinozoans indicate a range of middle Sheinwoodian to the upper Gorstian based on the single occurrence of *Conochitina tuba* (Nestor, 2012).

Rombouts (1976) and the resulting publication of Maes *et al.* (1978) interpreted the whole section along the southern pond of Parc de la Neuville as inverted: the sediments become older in southern direction and the bedding is to the south. Our data does not support Rombouts (1976).

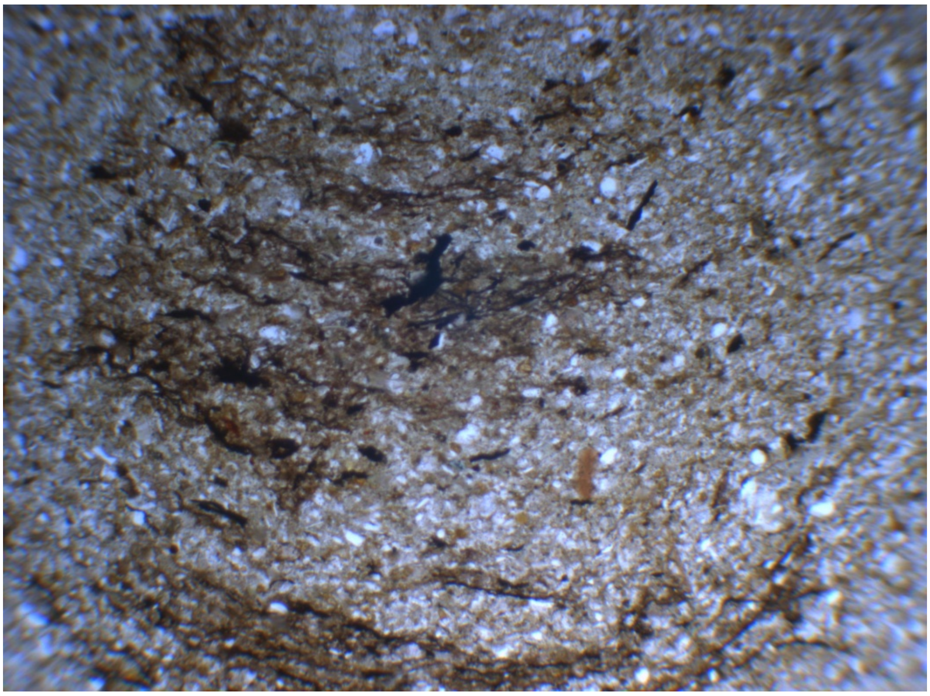


Fig. II.3.21. Thin section showing a possible feeding structure in unit a1.2. The minerals at the bottom of the thin section are located more northwards and the minerals at the top of the thin section are located more southwards. The picture is taken in plane-polarized light and it is 2 mm from left to right.

A sign of normal polarity have been found with younging of the layers in southerly direction in unit a1.2. In this unit 18 cm above the base of it, a thin section was made (see fig. II.3.21). It shows concave organic lines facing into northerly direction. It represents an ichnofacies with a burrowing structure. This indicates a younging of the layers into southerly direction.

Microravination was not observed by us and it can be questioned if this sedimentological feature can be used to describe the polarity in mudstone. No sandstones have been observed in the entire section, as this phenomenon is known in sandstones. Only mudstones are present. Laminae in mudstone can cut the underlying and covering laminae giving no indication of the polarity.

The graptolites occurring in unit a1.3 belong all to the *chimaera-scanicus* Biozone indicating no sign of polarity. The chitinozoans from unit a belong all to the middle Gorstian to lower part of the upper Gorstian. The graptolites in unit b indicate the upper Sheinwoodian. Hence older sediments are situated further southwards of unit a but in close contact between each other. This phenomenon is explained by a fault contact between unit a and unit b. This is corroborated with poorly exposure of the sediments over a length of 1.6 meters between unit a and unit b.

The age of unit c and unit d is not known and no polarity indicators have been found in these units.

Chitinozoan plates

Plate II.3.2. Chitinozoans from Neuville-sous-Huy, section Parc de la Neuville, southern part.

1. *Desmochitina* sp. L: 97 µm; Dp: 70 µm. JD 10-20. Unit a1.1.

2. *Eisenackitina toddingensis*. L: 100 µm; Dp: 78 µm; Dc: 52 µm. JD 10-20. Unit a1.1.

3. *Eisenackitina toddingensis*. L: 132 µm; Dp: 77 µm; Dc: 51 µm. JD 10-22. Unit a1.2.

4. *Belonechitina* sp. L: 153 µm; Dp: 71 µm; Dc: 43 µm. JD 10-29. Unit a2.

5. *Conochitina tuba*. L: 145 µm; Dp: 83 µm; Dc: 64 µm. JD 10-21. Unit a1.2.

6. *Conochitina rudda*. L: 140 µm; Dp: 62 µm; Dc: 46 µm. JD 10-21. Unit a1.2.

7. *Conochitina rudda*. L: 240 µm; Dp: 90 µm; Dc: 76 µm. JD 10-21. Unit a1.2.

8. *Conochitina rudda*. L: 130 µm; Dp: 65 µm; Dc: 40 µm. JD 10-28. Unit a2.

9. *Conochitina rudda*. L: 200 µm; Dp: 68 µm; Dc: 50 µm. JD 10-35. Unit a2.

10. *Conochitina pachycephala*. L: 270 µm; Dp: 56 µm. JD 10-22. Unit a1.2.

11. *Conochitina pachycephala*. L: 276 µm; Dp: 93 µm. JD 10-31. Unit a2.

12. *Conochitina pachycephala*. L: 340 µm; Dp: 82 µm; Dc: 52 µm. JD 10-33. Unit a2.

13. *Conochitina* cf. *pachycephala*. L: 217 µm; Dp: 83 µm. JD 10-29. Unit a2.

14. *Conochitina* cf. *pachycephala*. L: 202 µm; Dp: 61 µm; Dc: 43 µm. JD 10-30. Unit a2.

15. *Conochitina* cf. *pachycephala*. L: 290 µm; Dp: 70 µm. JD 10-33. Unit a2.

16. *Salopochitina* sp. L: 99 µm; Dp: 80 µm; Dc: 50 µm. JD 10-22. Unit a1.2.

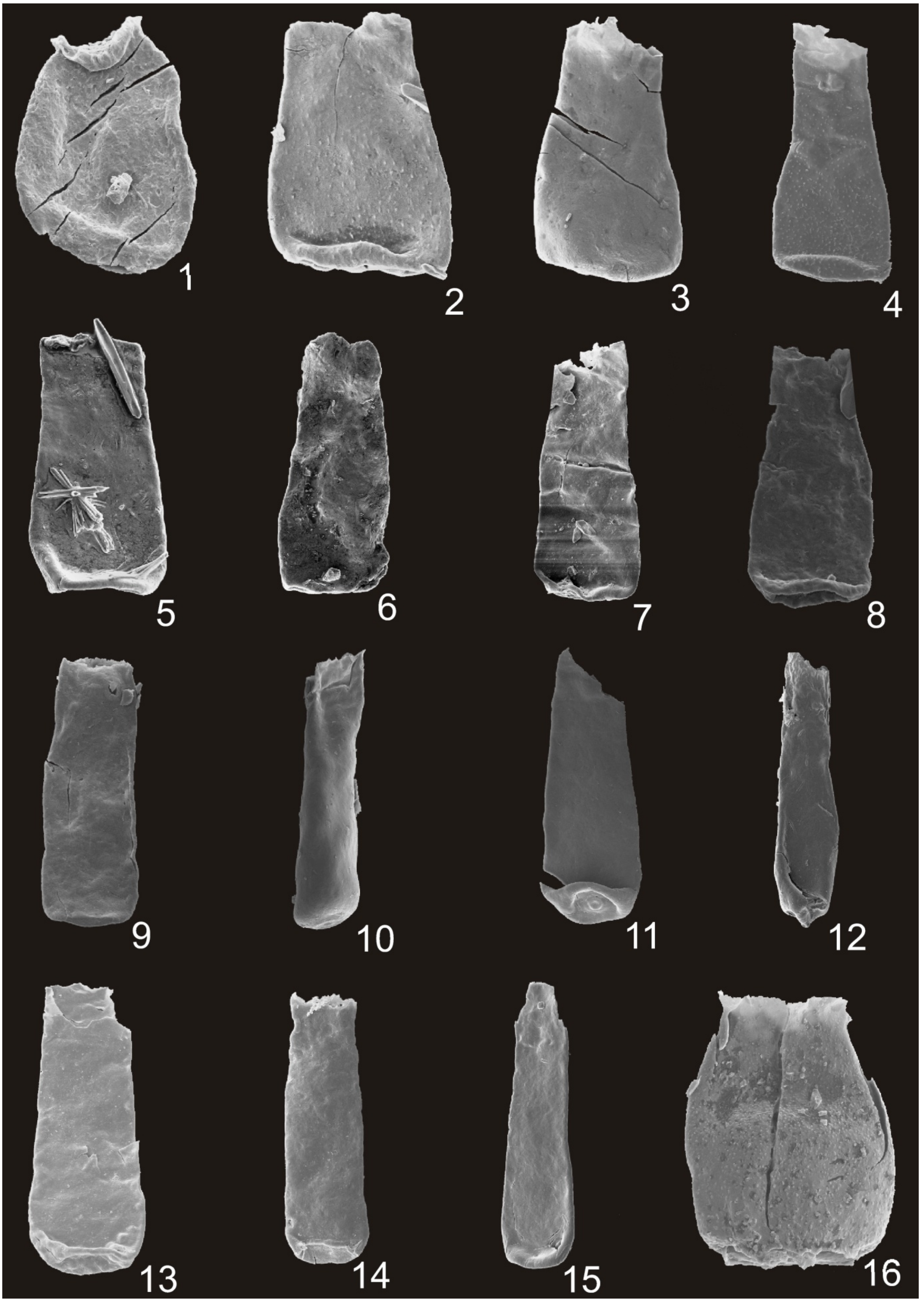


Plate II.3.2.

Plate II.3.3. Chitinozoans from Neuville-sous-Huy, section Parc de la Neuville, southern part.

1. *Conochitina claviformis*. L: 350 µm; Dp: 94 µm. JD 10-22. Unit a1.2.

2. *Conochitina claviformis*. L: 160 µm; Dp: 55 µm. JD 10-33. Unit a2.

3. *Sphaerochitina dubia*. L: 128 µm; Dp: 78 µm. Dc: 36 µm. JD 10-23. Unit a1.3.

4. *Sphaerochitina dubia*. L: 93 µm; Dp: 70 µm. Dc: 20 µm. JD 10-25. Unit a1.3.

5. *Sphaerochitina dubia*. L: 134 µm; Dp: 79 µm. Dc: 36 µm. JD 10-29. Unit a2.

6. *Sphaerochitina dubia*. L: 100 µm; Dp: 71 µm. Dc: 22 µm. JD 10-30. Unit a2.

7. *Sphaerochitina dubia*. L: 92 µm; Dp: 71 µm. Dc: 30 µm. JD 10-30. Unit a2.

8. *Sphaerochitina dubia*. L: 114 µm; Dp: 63 µm. Dc: 23 µm. JD 10-31. Unit a2.

9. *Angochitina milleri*. L: >210 µm; Dp: 74 µm. Dc: 34 µm. JD 10-23. Unit a1.3.

10. Detail of plate 2, picture 9 showing the spines of *Angochitina milleri*. JD 10-23. Unit a1.3.

11. *Angochitina milleri*. L: 187 µm; Dp: 67 µm. Dc: 30 µm. JD 10-24. Unit a1.3.

12. *Belonechitina lauensis*. L: 143 µm; Dp: 84 µm. Dc: ≤49 µm. JD 10-24. Unit a1.3.

13. *Belonechitina lauensis*. L: 180 µm; Dp: 70 µm. Dc: 27 µm. JD 10-26. Unit a1.3.

14. *Belonechitina* sp. L: 200 µm; Dp: 100 µm. Dc: 67 µm. JD 10-27. Unit a2.

15. *Conochitina pumilio*. L: 134 µm; Dp: 80 µm. Dc: 60 µm. JD 10-24. Unit a1.3.

16. *Conochitina pumilio*. L: 122 µm; Dp: 78 µm. Dc: 48 µm. JD 10-24. Unit a1.3.

Plate II.3.3.

Plate II.3.4. Chitinozoans from Neuville-sous-Huy, section Parc de la Neuville, southern part.

1. *Ancyrochitina* sp. L: 161 µm; Dp: 80 µm; Dc: 32 µm. JD 10-24. Unit a1.3.

2. *Ancyrochitina* sp. L: 128 µm; Dp: 71 µm; Dc: 35 µm. JD 10-24. Unit a1.3.

3. Chain of 2 specimens of *Cingulochitina* sp. 2. L_{total}: 174 µm. JD 10-26. Unit a1.3.

4. Chain of 2 specimens of *Cingulochitina* sp. 2. L_{total}: 135 µm. JD 10-26. Unit a1.3.

5. *Cingulochitina gorstyensis*. L: 75 µm; Dp: 65 µm; Dc: 34 µm. JD 10-27. Unit a2.

6. *Cingulochitina*? sp. 1. L: 140 µm; Dp: 107 µm; Dc: 58 µm. JD 10-28. Unit a2.

7. *Salopochitina* sp. 1. L: 110 µm; Dp: 90 µm; Dc: 43 µm. JD 10-30. Unit a2.

8. *Salopochitina* sp. 1. L: 140 µm; Dp: 94 µm; Dc: 47 µm. JD 10-31. Unit a2.

9. *Salopochitina* sp. 1. L: 91 µm; Dp: 79 µm; Dc: 42 µm. JD 10-35. Unit a2.

10. *Sphaerochitina* sp. 1. L: 152 µm; Dp: 69 µm; Dc: 32 µm. JD 10-32. Unit a2.

11. *Cingulochitina* sp. L: 122 µm; Dp: 78 µm; Dc: 37 µm. JD 10-33. Unit a2.

12. *Ancyrochitina* sp. L: 119 µm; Dp: 62 µm; Dc: 25 µm. JD 10-33. Unit a2.

13. *Fungochitina* sp. L: 108 µm; Dp: 75 µm; Dc: 26 µm. JD 10-35. Unit a2.

14. Chain of 3 specimens of *Calpichitina* sp. L_{total}: 186 µm. JD 10-35. Unit a2.

15. *Ancyrochitina* sp. L: 128 µm; Dp: 70 µm; Dc: 29 µm. JD 10-35. Unit a2.

16. *Ancyrochitina* sp. L: 117 µm; Dp: 69 µm; Dc: 28 µm. JD 10-35. Unit a2.

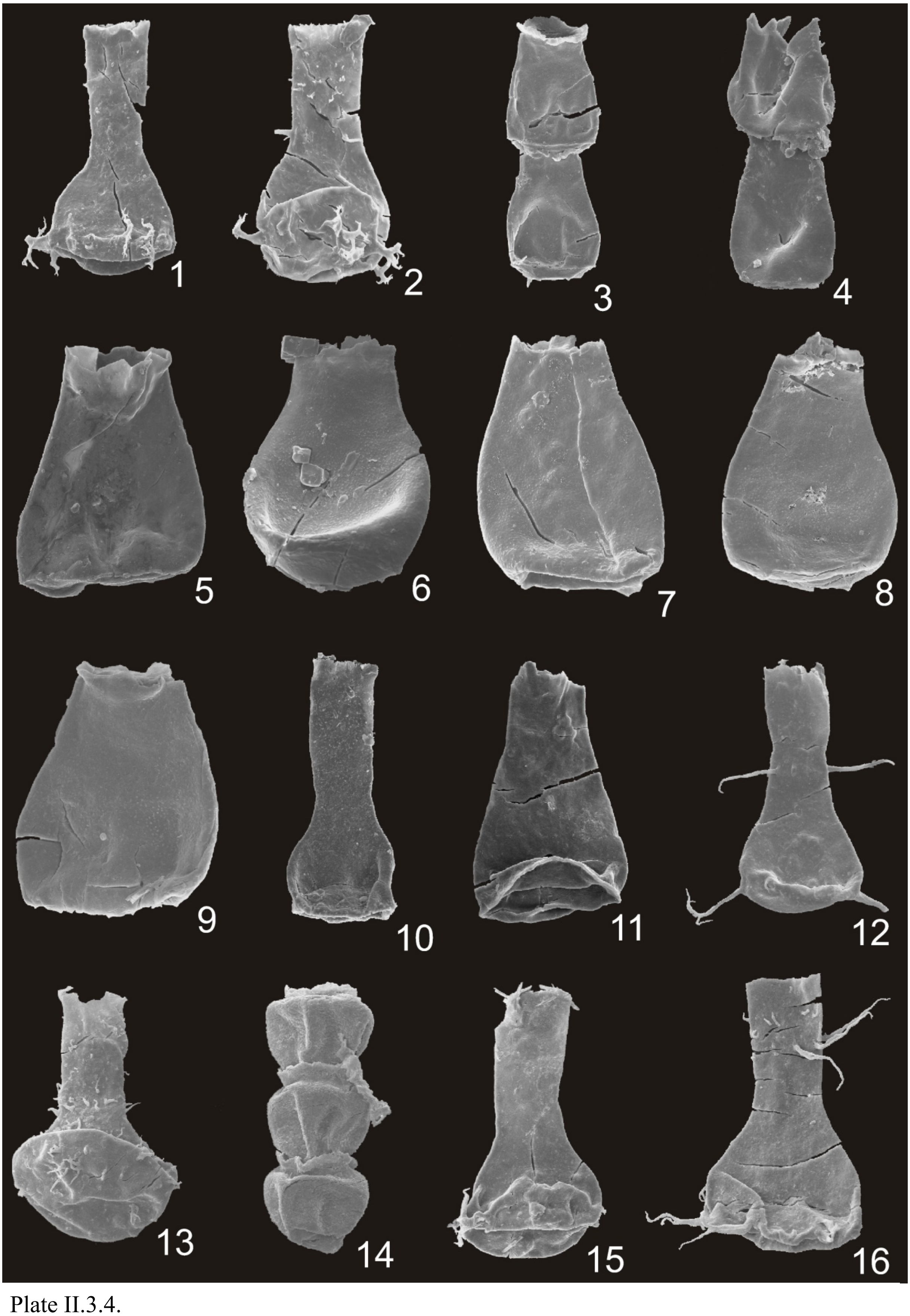


Plate II.3.4.

Plate II.3.5. Chitinozoans from Neuville-sous-Huy, section Parc de la Neuville, southern part.

1. *Conochitina claviformis*. L: 310 µm; Dp: 89 µm; Dc: ≤58 µm. JD 10-37. Unit b.

2. *Conochitina claviformis*. L: 220 µm; Dp: 56 µm; Dc: ≤30 µm. JD 10-40. Unit b.

3. *Conochitina claviformis*. L: 280 µm; Dp: 79 µm; Dc: ≤65 µm. JD 10-47B. Unit d.

4. *Conochitina* aff. *tuba*. L: 132 µm; Dp: 68 µm; Dc: ≤50 µm. JD 10-43. Unit b.

5. *Conochitina* aff. *tuba*. L: 137 µm; Dp: 63 µm; Dc: ≤46 µm. JD 10-43. Unit b.

6. *Conochitina* aff. *tuba*. L: 123 µm; Dp: 67 µm; Dc: ≤43 µm. JD 10-43. Unit b.

7. *Conochitina* aff. *tuba*. L: 150 µm; Dp: 67 µm; Dc: ≤50 µm. JD 10-43. Unit b.

8. *Conochitina* aff. *tuba*. L: 146 µm; Dp: 76 µm; Dc: ≤56 µm. JD 10-43. Unit b.

9. *Conochitina* cf. *gutta*. L: 144 µm; Dp: 81 µm; Dc: ≤55 µm. JD 10-43. Unit b.

10. *Ancyrochitina* sp. L: 130 µm; Dp: 77 µm; Dc: 32 µm. JD 10-46. Unit c.

11. *Cyathochitina* sp. L: >170 µm; Dp: 119 µm; Dc: 61 µm. JD 10-47B. Unit d.

12. *Bursachitina* sp. L: 123 µm; Dp: 74 µm; Dc: 29 µm. JD 10-47B. Unit d.

Plate II.3.5.

4. Neuville-sous-Huy, new road 300 m west of Parc de la Neuville

4.1. Location and description of the outcrop

The road is located approximately 300 m west of Parc de la Neuville. The road has been constructed in 2005 and before no outcrops were visible. The section have been first studied by Deckers (2011) during his M.Sc. thesis and reevaluated and restudied during our PhD study. A part of the results are presented at an international conference (Mortier *et al.*, 2012a). The outcrop starts approximately 430 meters southwards from the N90 along the new road and is approximately 200 meters long. A datum point, from where all the outcrops has been located, has been located exactly in the continuation of the northern boundary of the parcel with trees. Weathering is strongly present in the outcrops making the rocks brownish in most cases. In fig. II.4.1 a map of the section is present.

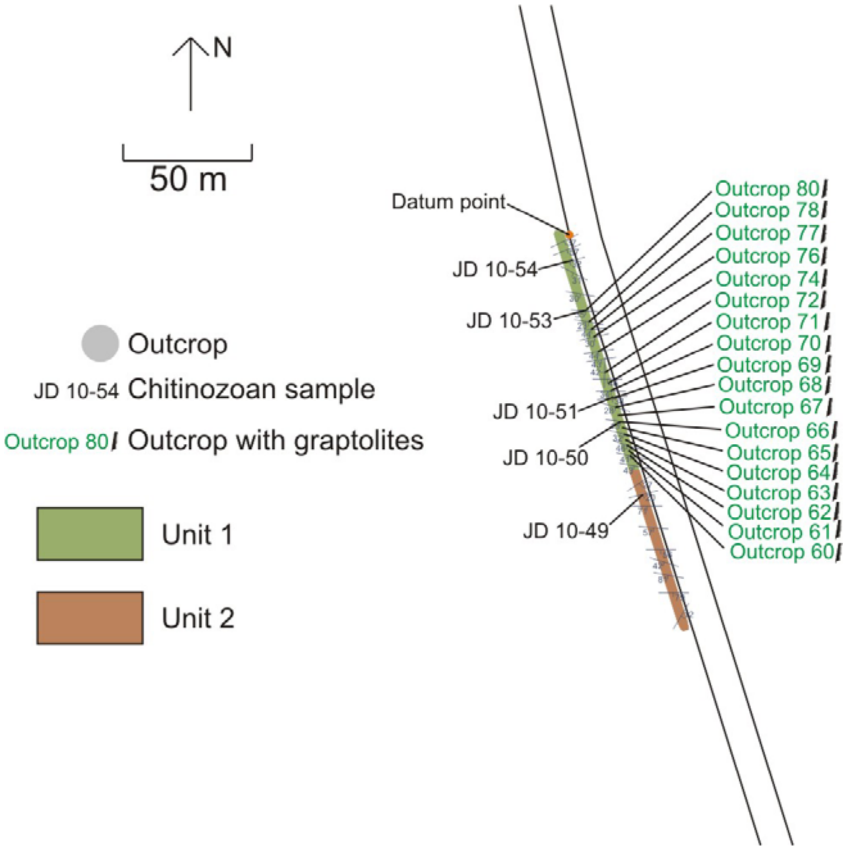


Fig. II.4.1. Map of the section new road 300 m west of Parc de la Neuville.

4.2. Lithological results

From north to south the following units crop out.

Unit 1

Unit 1 outcrops from 2.9 meters north of the datum point to 85.9 meters southwards of the datum point. It contains dark grey, finely laminated mudstone, in most cases weathered to a brownish to pale grey colour. They can be described as laminated hemipelagites. In the northern part occur more frequently dark grey, compact mudstones intercalated with the laminated mudstone. These compact mudstones are up to one centimeter thick. Many graptolite levels do occur in these laminated mudstone. In the northern part the outcrop is less weathered with an average bedding of Strike 090/ Dip 38S. A deformed zone do occur (see chapter 4.3) 48 meters southwards of the datum point. Southwards of the deformed zone the bedding is quite uniformly again and has an average of Strike 100/Dip 39S. The total thickness of this unit is estimated at approximately 51 meters. Several levels with graptolites have been discovered together with one level containing a possible Conularia.

In this unit five, pale clay levels occur parallel with the bedding of the surrounding rocks with a thickness of a few millimeter to centimeter (fig. II.4.2.). From one of these layers a thin section has been made (see chapter 4.4).

Fig. II.4.2. A clay level in the outcrop. It is located 70.5 m to the south of the datum point.

Unit 2

Grey-green compact mudstone occurs over a distance of 64.6 meters. In between unit 2 and bounded by faults the same lithology as of unit 1 occurs 10.8 meters southwards of the contact between unit 1 and unit 2 and over a distance of 2.9 meters. It is followed southwards again by grey-green compact mudstone. The contact between unit 1 and unit 2 is possibly by fault. The outcrops of unit 2 are not well exposed and strongly weathered causing the rocks to have a brownish colour. Hence a thickness estimate is not possible.

4.3. Tectonic deformation

Fig. II.4.3. View of the deformed zone. This zone is 5.9 meters long.

48 meters to the south of the datum point a subvertical fault is visible. Southwards of it a deformed zone occur interrupting the continuous bedding to the south. Southwards of this fault the beds are sub horizontal going into an antiform that is cut by multipe north dipping faults (fig. II.4.3 and fig. II.4.4). The deformed zone is present over a length of 5.9 meters. The study of this antiform is hampered by places where the outcrop is hardly visible and only loose rocks are present.

4.4. Study of the clay layer

One clay layer, present at 70.5 m southwards of point zero, has been studied by thin section (these of fig. II.4.2). The clay layer contains larger minerals up to 150 µm in comparison with the neighboring laminated layers. We could identify angular crystals of quartz, plagioclase and opaque minerals. The angular nature of the crystals proves the volcaniclastic origin of this layer. Most likely the other clay layers have also a volcaniclastic origin.

Fig. II.4.4. A more detailed view of the antiform.

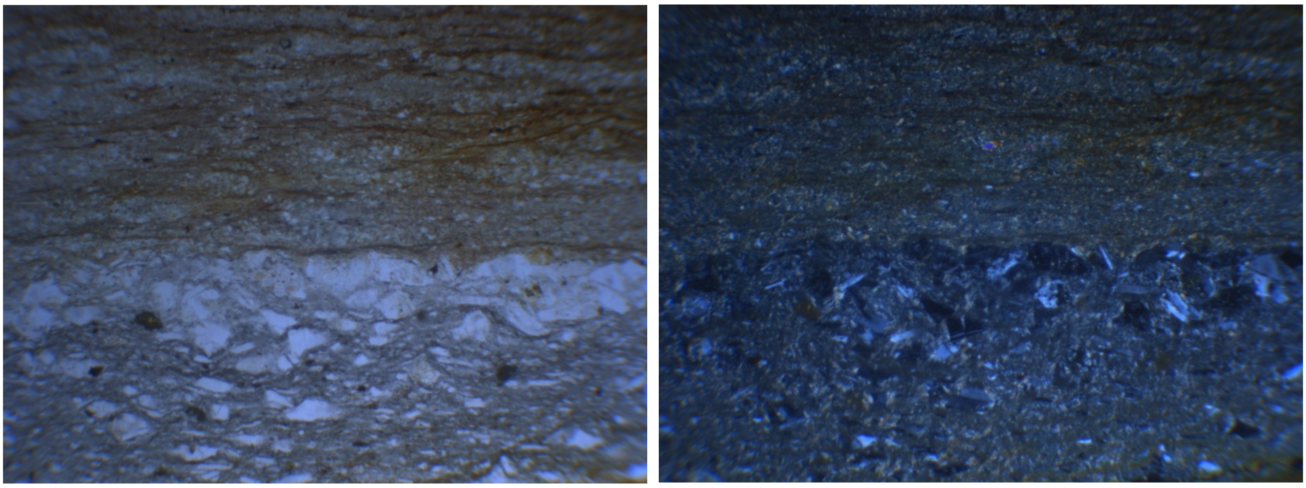


Fig. II.4.5. Picture of the thin section made from the clay layer. The contact with the neighboring laminated mudstone can be seen. Large crystals of mainly plagioclase and quartz can be seen. The image is 2 mm from left to right. The image on the left is taken in plane-polarized light; the image on the right is taken with crossed polars.

4.5. Chitinozoan results

Unit	Sample number	*Conochitina* spp.	*Sphaerochitina dubia*	*Sphaerochitina lycoperdoides*	*Sphaerochitina* spp.	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
1	JD 10-54		1	1	2	2	6	38.06	0.16
	JD 10-53						0	35.52	0.00
	JD 10-52						0	37.35	0.00
	JD 10-51						0	35.47	0.00
	JD 10-50						0	36.54	0.00
2	JD 10-49	1				2	3	36.17	0.08
	JD 10-48	1				3	4	35.09	0.11
Total		2	1	1	2	7	13	254.20	0.05

Table II.4.1. Chitinozoan results of Neuville-sous-Huy, new road 300 m west of Parc de la Neuville.

A preliminary study has been done with a total of 13 specimens in 7 samples (see table II.4.1.). Four of the seven samples are barren. The other three samples contain chitinozoans that are poorly preserved and not abundant with less than 1 chitinozoan per gram of rock.

Unit 1

Four of the five samples are barren. In the other sample, sample JD 10-54, one specimen of *Sphaerochitina dubia*, one specimen of *Sphaerochitina lycoperdoides* and *Sphaerochitina* spp. occur.

Unit 2

Only few chitinozoans are preserved in the two samples of this unit and they are all poorly preserved. Only two *Conochitina* spp. are present besides five undeterminable chitinozoans.

Discussion on bio- and chronostratigraphy with chitinozoans

Four of the five samples do not contain any chitinozoans in unit 1. In the other sample, JD 10-54, one *Sphaerochitina dubia* and one *Sphaerochitina lycoperdoides* do occur. *Sphaerochitina lycoperdoides* occurs in the upper Homerian (Verniers *et al.*, 1995 & Nestor, 2012) where it has his total range biozone. Hence we can conclude that sample JD 10-54 from unit 1 belongs to the *Sphaerochitina lycoperdoides* Biozone of the upper Homerian. Grahn (1996) found this species to occur even higher up into the lower Gorstian. Hence we cannot exclude that sample JD 10-54 ranges up into the lower Gorstian.

Unit 2 contains only two specimens of *Conochitina* spp., and five undeterminable chitinozoans. Hence we can conclude an Ordovician to Silurian age (Paris *et al.*, 1999).

4.6. Graptolite results

Graptolites have been found in a total of 18 levels scattered over 18 outcrops all belonging to unit 1. The graptolites are studied and identified by Prof. Dr. Petr Storch (Institute of Geology AS CR, Prague, Czech Republic). The results of the identifications is given in table 4.2.

Unit	Outcrop	*Monoclimacis flumendosae*	*Streptograptus antennularius*	*Monograptus flemingii*	*Streptograptus retroflexus*	*Pristiograptus dubius frequens*	*Monoclimacis* spp.	*Pristiograptus pseudodubius*	*Pristiograptus dubius*	*Cyrtograptus lundgreni*	*Monograptus* ex gr. *priodon*	*Pristiograptus longus*	*Pristiograptus* ex gr. *dubius*	*Monograptus* spp.	*Pristiograptus* spp.	*Monograptus riccartonensis*	graptolite indet.	*Parakionoceras* spp.	nautiloid fragments	nautiloid shell fragment	sponge spicules	Graptolite biozonation
	Outcrop 60			aff.									X				X		X		X	*rigidus-lundgreni*
	Outcrop 61															aff.			X			?
	Outcrop 62								cf.		X											*rigidus-lundgreni*
	Outcrop 63													X	X			X				*rigidus-lundgreni*
	Outcrop 64												X									*rigidus-lundgreni*
	Outcrop 65			X							X	cf.										*rigidus-lundgreni*
	Outcrop 66																X					?
	Outcrop 67																X	X				?
1	Outcrop 68										X											*rigidus-lundgreni*
	Outcrop 69		cf.	X	aff.			X		X												*lundgreni*
	Outcrop 70				aff.			X												X		*rigidus-lundgreni*
	Outcrop 71								X													*rigidus-lundgreni*
	Outcrop 72						X	X														*rigidus-lundgreni*
	Outcrop 74					cf.											X					?
	Outcrop 76			aff.	X																	*rigidus-lundgreni*
	Outcrop 77																X					?
	Outcrop 78																X					?
	Outcrop 80	aff.	aff.																			*rigidus-lundgreni*

Table II.4.2. Graptolite results of Neuville-sous-Huy, new road 300 m west of Parc de la Neuville.

Many graptolite levels can be situated in the *Cyrtograptus rigidus* Biozone – *Cyrtograptus lundgreni* Biozone indicating the upper Sheinwoodian to lower Homerian. The graptolite level from outcrop 69 belongs to the *Cyrtograptus lundgreni* Biozone of the lower Homerian.

4.7. Discussion

The relationship between the different outcrops is not known, except for sharing the same lithology. No polarity have been found so we don’t know in which direction the layers are younger.

In unit 1 one graptolite level of outcrop 69 belongs to *Cyrtograptus lundgreni* Biozone of the lower Homerian. Many other graptolite levels belong to the *Cyrtograptus rigidus* Biozone – *Cyrtograptus lundgreni* Biozone indicating the upper Sheinwoodian to lower Homerian. The chitinozoan *Sphaerochitina lycoperdoides* has been found indicating the upper Homerian, possibly up to the lower Gorstian in a sample located approximately 20 meters more northwards from the most northerly graptolite level. This is still not in contradiction with the graptolite results as the exact relationship between the different outcrops is not known. Hence for unit 1 we can say that it ranges from the upper Sheinwoodian up to the upper Homerian to possibly the lower Gorstian.

Unit 2 can be situated in the Ordovician to Silurian.

Chitinozoan plates

Plate II.4.1. Chitinozoans from Neuville-sous-Huy, section new road 300 m west of Parc de la Neuville.

1. *Sphaerochitina dubia*. L: 108 µm; Dp: 89 µm; Dc: 32 µm. JD 10-54. Unit 1.

2. *Sphaerochitina lycoperdoides*. L: 111 µm; Dp: 88 µm; Dc: 40 µm. JD 10-54. Unit 1.

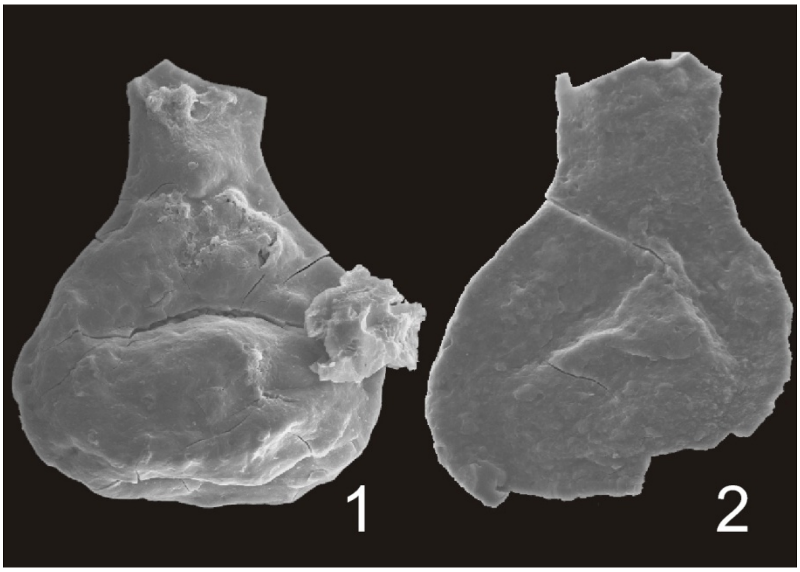


Plate II.4.1.

5. Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville

5.1. Location

The section is situated about 700 m east of Parc de la Neuville, in a north-south orientated ravine 1-10 m deep on a steep slope of the flank of the Meuse valley. Along the brooklet outcrops are almost continuously visible, especially in the northern part. In the north some outcrops are present along a east-west orientated path away from the brooklet.

5.2. Earlier studies

The section attracted initially the attention of the geologists by the presence of many volcaniclastic layers of which were thought to be extrusive rock. The studies by previous authors concerning the volcaniclastic layers will be discussed in chapter II.7. In this chapter we will focus on the sedimentary layers.

Michot (1932a) described the rocks in the ravine as follows. In the brooklet a series of green shale occur containing intercalations of sandy beds and some rhyolitic or keratophyric flows together with multiple layers of red shales. The layers, in general, dip 40° to the south. Eight meters above the first level of red shales he found the following graptolites: *Monograptus vomerinus*, *var. crenulatus* and *Monograptus spiralis*. They indicate according to him the *Monograptus crenulatus* Biozone.

Keratophyre is the name used for a rock containing dominantly of sodium feldspar (Corin, 1965).

Southwards of this unit, that is outcropping in the ravine, along a path he found the following going southwards.

a. Abundant debris of rhyolite indicating the presence of an outcrop with this lithology nearby.

b. Green shale with an intercalation of red shale. This unit is interrupted at the end by a fault.

c. Finely laminated shale, slightly sandy with a reddish hue. It contains the following graptolites: *Cyrtograptus murchisoni*, *Monograptus vomerinus*, *Monograptus vomerinus*, *var. basilicus*, *Monograptus priodon* and *Monograptus dubius*. It belongs according to him to the *Cyrtograptus murchisoni* Biozone. The contact between unit 3 and unit 4 is by a fault.

The same author, in 1934, added more detail to the previous description. He divided the section in the following units (the same numbering has been used) going from north to south (see also fig. II.3.3):

a. Starting from the alluvial plain of the Meuse and 400 m going upstream in the brooklet, bluish to greenish, siliceous, very compact shales occurs. They give, according to him, the impression of being cooked.

b. A bed of eruptive rock with the petrographic characteristics of a keratophyre with a thickness of about 1 m. The relationship with the neighbouring shales is unclear. This eruptive rock, occurring on the eastern flank of the valley, dip 30° to 40° to the south as is the same for the neighbouring shale beds.

c. Bluish, sandy shale, dipping 50° to the south, over a length of 40 meters, with a thickness of 30 meters.

d. A bed of keratophyric rock, nicely interstratified with a thickness of 0.75 m. This bed is covered by a mainly sericitic shale with a thickness of 0.20 m.

e. Bluish, sometimes blackish, compact or finely laminated shale, visible over a length of 10 meters, with a thickness of 7.5 meters.

f. An "arkose" with a fine grain size and a clayey cement with a thickness of 1 meter.

g. Green or bluish, sometimes finely laminated shale, containing locally small intercalations of sandstone. It is visible over a length of 40 meters, with a thickness of 30 meters. Five meters above the base a bed of red shale occurs with a thickness of approximately 2 meters. At eight meters he found the same graptolites as mentioned by himself in 1932a and where he concluded that it belongs to the *Monograptus crenulatus* Biozone.

h. Beds of quartz-bearing keratophyre with small intercalations of sericitic shale with a thickness of 3 to 5 cm. The beds dip 50° to the south with the same orientation as that of the shale. The total thickness of this unit is 4 meters.

i. Along the path abundant debris of green and red shale are observed with a thickness of approximately 20 meters.

j. In the talus he observed voluminous debris of quartz-bearing keratophyre. It indicates that this lithology is close to the surface.

k. Directly to the south green shale occurs containing a bed of red shale. At the top it is interrupted by a fault. The thickness of this unit is 4 meters.

l. Finely laminated, reddish shale ("schistes phylladeux roux") with the list of the same graptolites mentioned by Michot (1932a) and the conclusion that it belongs to the *Cyrtograptus murchisoni* Biozone. These shales outcrop over a few meters and are hidden further southwards.

He concluded that four eruptive rocks occur (the four keratophyre levels), all interbedded in between the shale. They are all formed under water.

Martin (1966, 1969a) studied the acritarchs in seven samples in the section (see fig. II.3.4). She gives a description of the acritarchs that are present defined in the units by Michot (1934).

Van Doorne (1975), in his Master thesis, made a description of the section starting from the northern edge of the bridge over the brooklet, taking this as zero datum point, and going southwards. He has also made a correlation of his observations with these of Michot (1934).

0-10 m: no outcrop present.

10-16 m: olive green, very finely laminated shale corresponding to unit a of Michot (1934).

26-28.6 m: Chlorite bearing, very hard and very fine-grained rock questioning if it is a tuff. Michot (1934) has described it as a keratophyre.

29.4 m: Green-blue to olive green shale, with a thickness of 3.2 m.

33.8 m: Olive green shale, with a thickness of 0.23 m.

35.5 m: Pale green to olive green shale, with a thickness of 10.5 m.

50.5 m: Green shale with after 1.35 m a 5 mm thick brown layer. The total thickness is 3.98 m.

58.4 m: Black, very fine-grained shale with a thickness of 4.12 m.

63.9 m: Outcrop of the quartz bearing keratophyre of unit d of Michot (1934) with a thickness of 1.2 m.

It is followed by a decimetric alternation of dark blue shale (corresponding to unit e of Michot, 1934) and green shale. The contact between the dark blue and the green shale is parallel to the bedding. The outcrop of this unit continues until 68 m.

70 m: Centrimetric to metric alternation of olive green, grey green, dark blue, brown, brown yellow and purple red shale with a total thickness of 38.19 m. It corresponds with unit g of Michot (1934) and the Michot (1934) found at 79.8 m a graptolite level belonging to the *crenulatus* Biozone. 7.57 m below the top a 4 cm thick sandstone bed occurs. Fifty centimeters above the base sandstone beds occur fining upwards with a total thickness of 1.3 m; this corresponds maybe to unit f, the “arkose” of Michot (1934).

Above this unit a 4.10 m thick level of tuff occurs corresponding to level h of Michot (1934). The outcrop continues until 118.3 meters. Further southwards debris of green and red shale and debris of keratophyre have been found without finding the outcrop.

155.3 m: Purple red shale with a thickness of 1.39 m followed by green shale with a thickness of 0.34 m. It corresponds to unit k of Michot (1934) where the latter found graptolites indicating the *murchisoni* Biozone. The outcrop of this unit continues until 157.6 m.

181.5 m: Centrimetric to decimetric alternation of purple red and olive green shale.

After 200 m the brooklet divides upstream into a western and eastern branch. South of the head of the branching olive green shale outcrop, with a finer grain size than these in the previous outcrop.

At the eastern branch 211.2 m he sees an outcrop of a tuff. Further to the south sporadically outcrops of olive green laminated shale occurs.

Vandevelde (1976), in her Master thesis, and the resulting publication of Maes *et al.* (1978), has used a different numbering than these of Michot (1934). New in their research is a new collection of graptolites and a new identification of them by B. Rickards together with describing the lithology. The section is in fig. II.5.1 and the litho-, bio- and chronostratigraphy is given in fig. II.5.2 both from Vandevelde (1976). She describes the section as follows (from north to south):

Unit A: dark grey to grey-green, quartzitic shale with a minimal thickness of approximately 6 meters.

Unit A-B: transition zone between unit 1 and unit 3 with mainly beds of unit 1 and intercalations of beds of unit 3. The unit has a thickness of approximately 8 meters. It contains three volcaniclastic layers.

Unit B: olive green to grey-green shale, weakly micaceous, with red shale that occurs at the top. On regular intervals the shales are laminated by blue-grey shales. The unit has a thickness of approximately 40 meters.

Unit B-C: transition zone between unit 3 and unit 5. It is interrupted by a thrust fault and the unit has a minimal thickness of 7 meters.

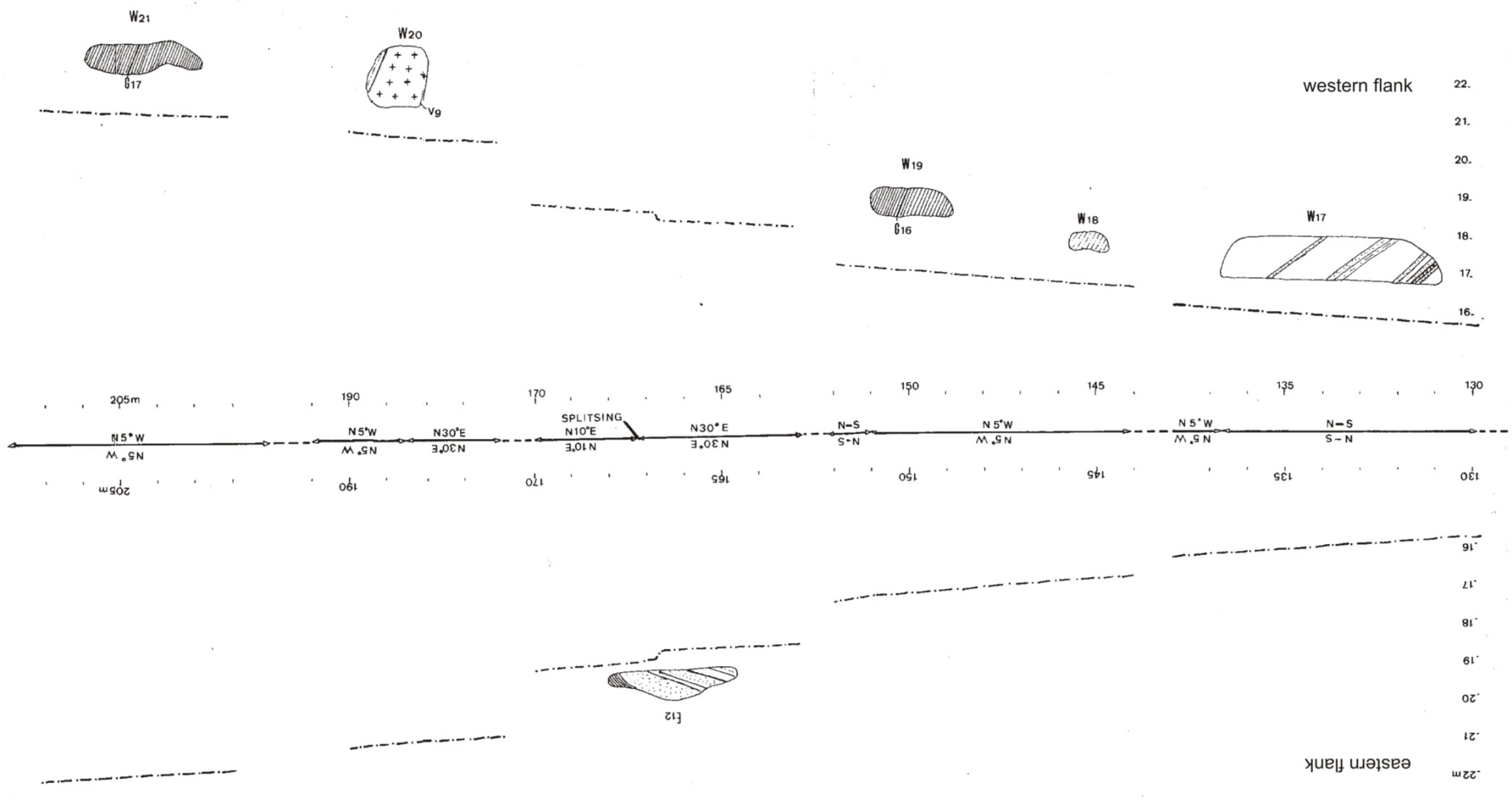
Unit C: olive green to dark grey-green shale and red shale with intercalations of sandy shale and sandstone. The intercalations become rarer towards the top. The unit has a thickness of approximately 60 meters.

Unit C-D: transition zone with beds of unit 5 and unit 7. At its top the transition zone is bounded by a thrust fault. The unit has a minimal thickness of 30 meters.

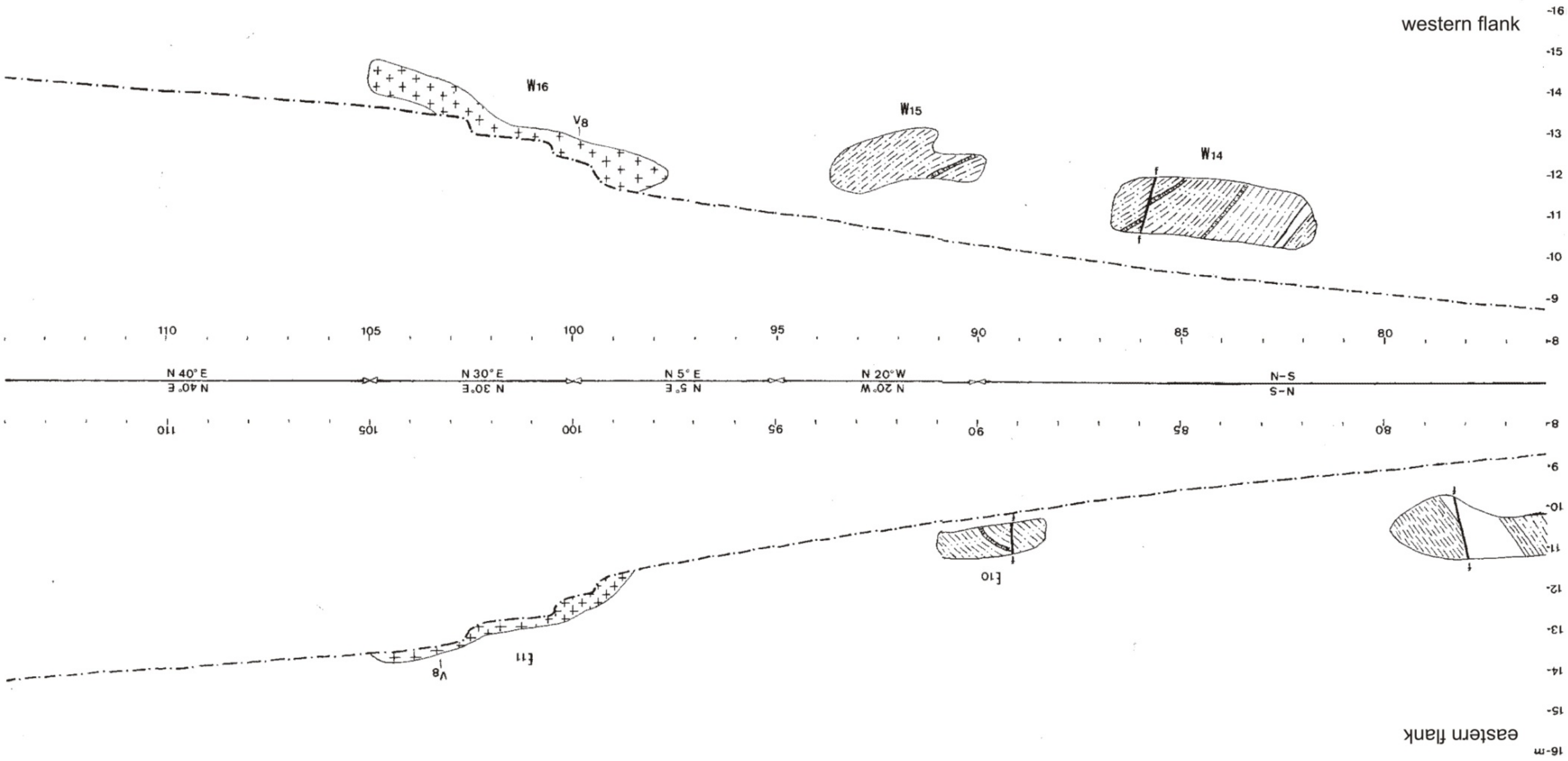
Unit D: blue-grey to grey-brown, sandy, laminated shale with a minimal thickness of 10 meters.

A normal sequence of deposits is present, always dipping to the south with a mean dipping of 40° to 60°. The total thickness is approximately 140 to 170 meters. There is the presence of some thrust faults.

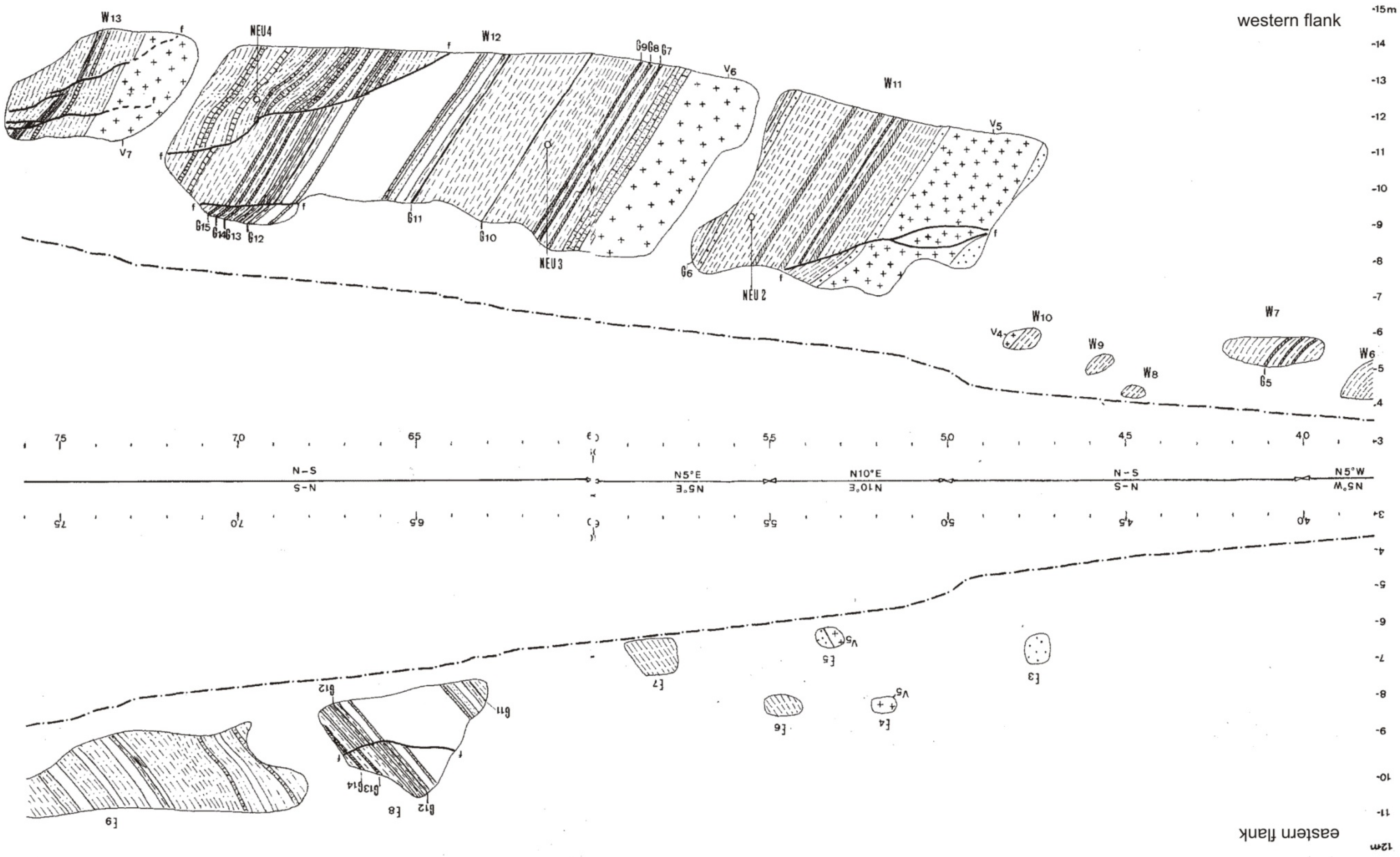
The thickness of the red shale observed in the section is maximum 2 meters thick.



western flank
W21
G17
W20
V9
W19
G16
W18
W17
22.
21.
20.
19.
18.
17.
16.
205m
190
170
165
150
145
135
130
SPLITSING
N5° W
N5°W
N30°E
N10°E
N30° E
N-S
N 5°W
N 5° W
N-S



western flank
W16
W15
W14
V8
110
105
100
95
90
85
80
N 40° E
N 30° E
N 5° E
N 20° W
N–S
eastern flank


western flank
W13
NEU4
W12
G9G8 G7
V6
W11
V5
V7
G15 G14G13 G12
G11
G10
NEU 3
G6
NEU 2
W10
V4
W9
W8
W7
G5
W6
N-S
N5°E
N10°E
N-S
N5°W
eastern flank

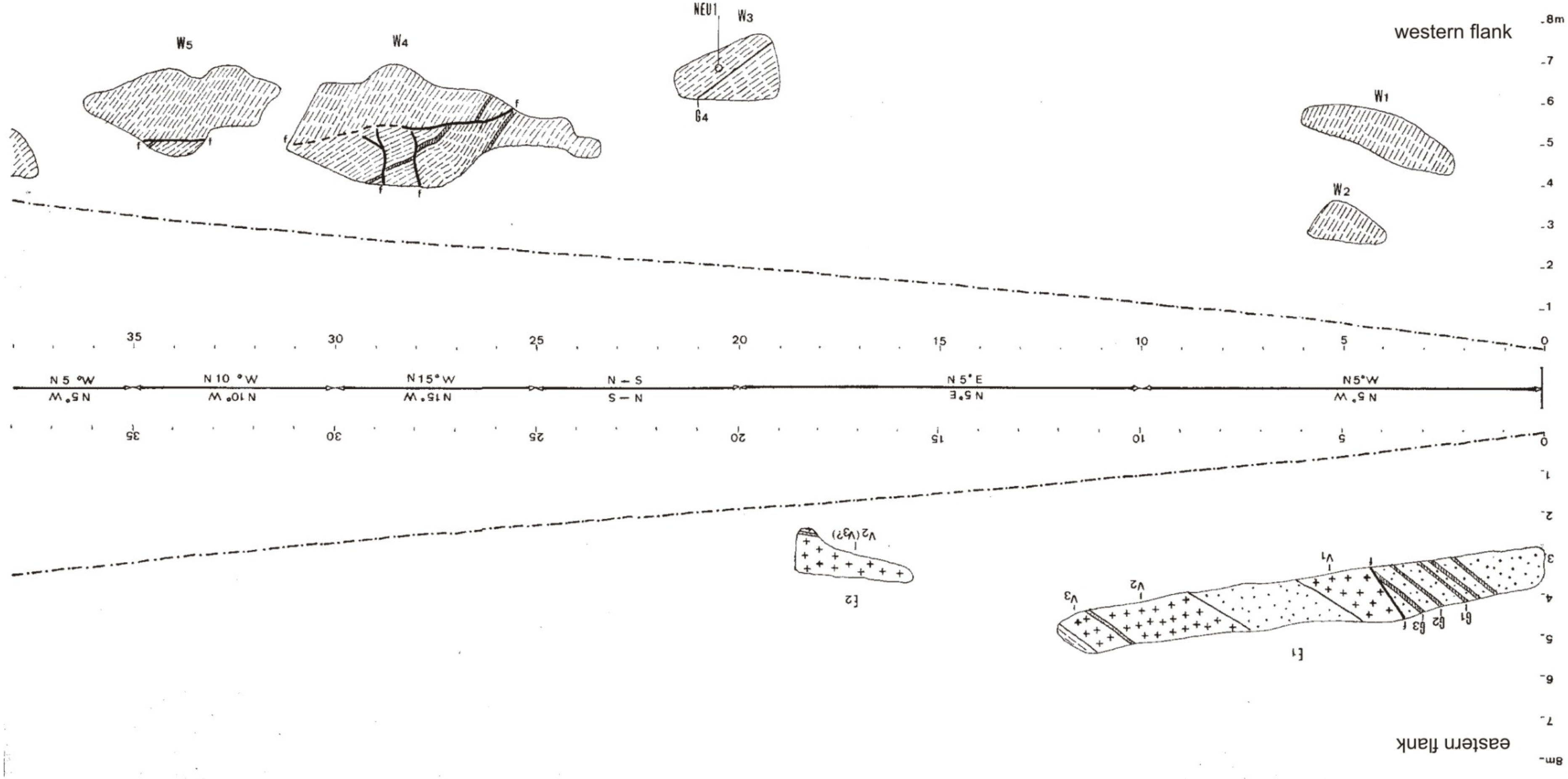

western flank
eastern flank
W5
W4
NEU1
W3
G4
W1
W2
N 5 °W
N 10 °W
N15°W
N – S
N 5° E
N5°W
E1
E2
V1
V2
V3
V2 (V3?)
G1
G2
G3
8m

Fig. II.5.1. Section of Neuville-sous-Huy, ravine 700 m east from south to north according to Vandevelde, 1976. Modified from Vandevelde, 1976.

From unit 1 until the lower part of unit 5 the units are nearly continuously exposed. From the upper part of unit 5 up to unit 7 only scattered outcrops are present.

The rocks of unit 1 up to unit 5 belong to the Dave Formation, these from unit 6 and unit7 belong to the Naninne Formation. A difference is made by Maes *et al.* (1978) who classifies unit 7 in the Jonquoi Formation.

Nine volcaniclastic layers have been described, four more than Michot (1934). A description of these volcaniclastic layers is found in table II.7.1.

Seventeen graptolite levels were described. Their graptolite content and their assignment into biozones is described in table II.5.1.

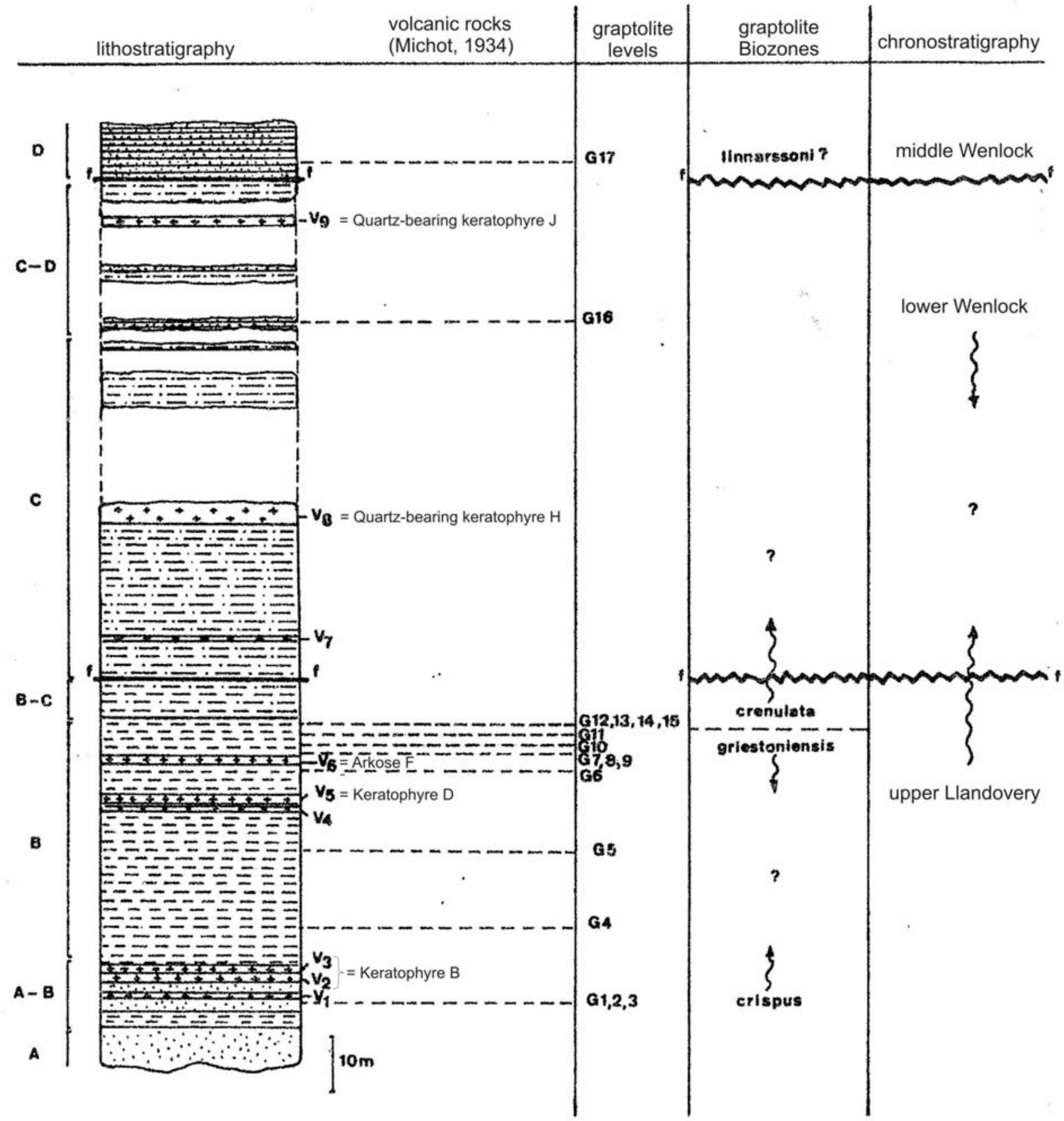
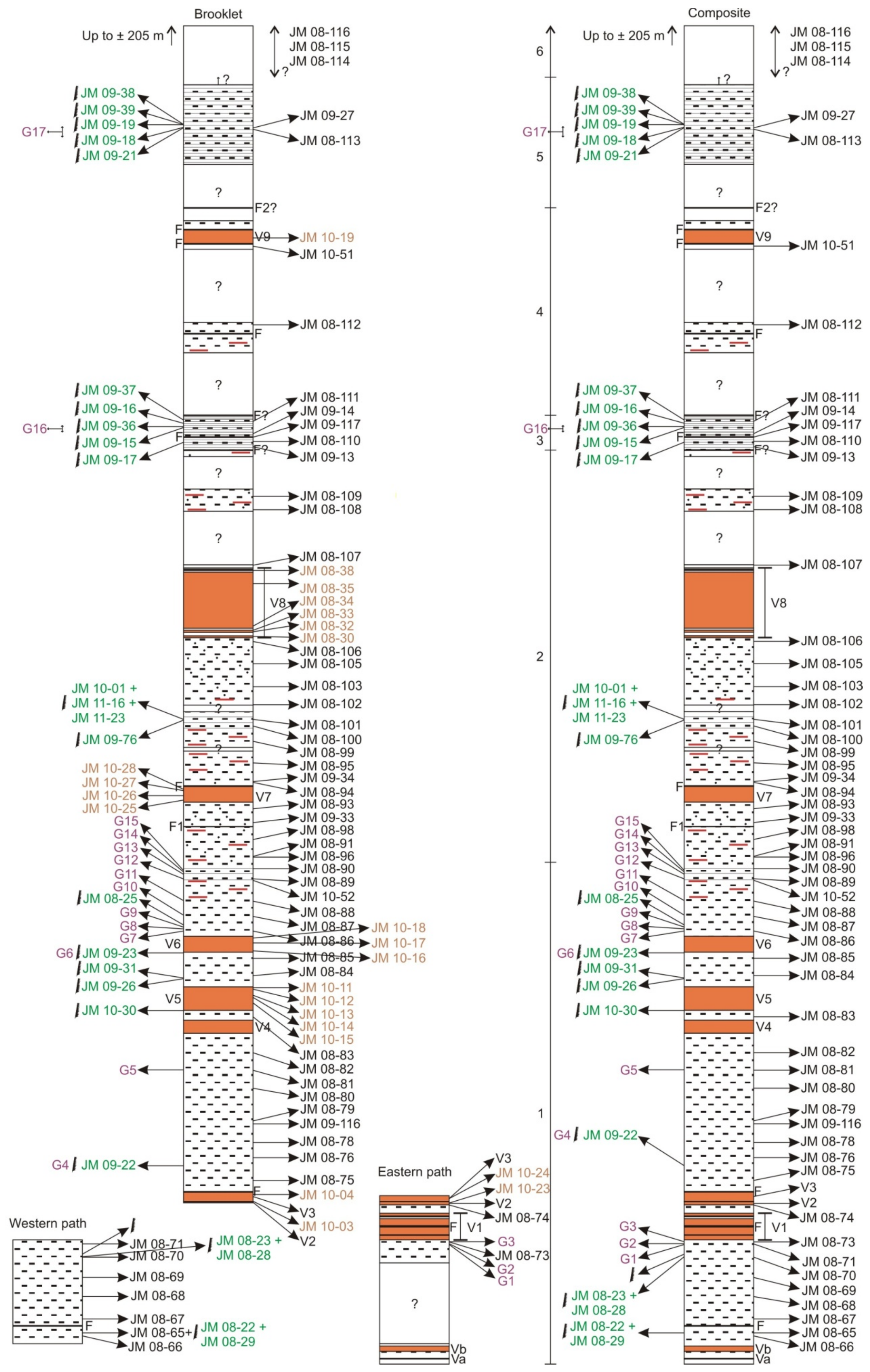


Fig. II.5.2. Litho-, bio-, and chronostratigraphy of the section Neuville-sous-Huy, ravine 700 m east. Modified from Vandevelde, 1976.

Graptolite level	unit	Graptolites	Graptolite Biozone
G17	7	*Pristiograptus dubius*, *Monograptus flemingii*, *Monoclimacis flumendosae*, *Cyrtograptus cladium*, *Cyrtograptus* cf. *linnarsoni*, *Pristiograptus* cf. *meneghini*, *Pristiograptus* sp., *Plectograptus* sp.	*linnarsoni* Biozone
G16	6	*Monograptus priodon*, *Monograptus vomerina*, *Retiolites geinitzianus*, *Cyrtograptus caladium*, *Monograptus* cf. *linnarsoni*, *Monograptus*	It is not possible to assign to a specific biozone but it

		vomerina cf. *vomerina*, *Monograptus* sp., *Monoclimacis* sp., *Retiolites* sp.	belongs to the lower Wenlock.
G15	3	*Monograptus griestoniensis*, *Monograptus spiralis*, *Monograptus vomerina*, *Monoclimacis* sp.	*crenulata* Biozone
G14	3	*Monograptus priodon*	
G13	3	*Pristiograptus nudus*, *Monograptus spiralis*, *Pristiograptus nudus*, *Monograptus* cf. *discus*, *Monograptus* cf. *priodon*, *Monograptus* cf. *rickardsi*, *Monoclimacis* cf. *crenulata*	
G12	3	*Monograptus spiralis*, *Retiolites geinitzianus*, *Monoclimacis* cf. *crenulata*, *Monograptus discus*, *Diversograptus* cf. *ramosus*	
G11	3	*Pristiograptus nudus*, *Monograptus spiralis*, *Monograptus discus*, *Monograptus priodon*, *Monograptus* cf. *griestoniensis*, *Monograptus* cf. *rickardsi*, *Diversograptus* cf. *ramosus*, *Monoclimacis* sp.	*griestoniensis* Biozone
G10	3	*Pristiograptus nudus*, *Monograptus rickardsi*, *Monograptus discus*, *Monograptus* cf. *parapriodon*, *Diversograptus* sp., *Monoclimacis* sp.	*griestoniensis* Biozone
G9	3	*Monograptus priodon*	*griestoniensis* Biozone.
G8	3	*Monograptus spiralis*, *Monograptus* cf. *exiguus*, *Monograptus* cf. *griestoniensis*, *Pristiograptus* sp.	
G7	3	*Monograptus marri*, *Monograptus priodon*, *Monograptus spiralis*, *Monoclimacis* cf. *crenulata*, *Monograptus* cf. *pragensis*, *Monograptus* sp.	
G6	3	*Monograptus priodon*, *Monograptus spiralis*, *Monograptus vomerina*, *Monograptus* cf. *nudus*	Not possible to indicate precisely a graptolite biozone. But taking into account the covering levels we can situate this level in the *crispus* or *griestoniensis* Biozone.
G5	3	*Monograptus marri*, *Monograptus* cf. *parapriodon*	
G4	3	*Pristiograptus nudus*, *Monograptus marri*, *Monograptus* cf. *spiralis*	*crispus* Biozone
G3	2	*Pristiograptus nudus*, *Monograptus* cf. *rickardsi*, *Monograptus* sp.	Post-*turricalatus*. In correlation with level G4 we can situate it in the *crispus* Biozone
G2	2	*Monograptus* sp.	
G1	2	*Pristiograptus nudus*, *Monograptus* sp.	

Table II.5.1. The seventeen graptolite levels, their graptolite content by identifications of B. Rickards and their assignment into a Biozone all in Vandevelde (1976). The same numbering has been used as Vandevelde (1976). The assignment into biozones is according the scheme of Rickards (1976).


Brooklet
Composite
Western path
Eastern path
Up to ± 205 m
10 m
JM 08-116
JM 08-115
JM 08-114
JM 09-38
JM 09-39
JM 09-19
JM 09-18
JM 09-21
G17
JM 09-27
JM 08-113
F2?
V9
JM 10-19
JM 10-51
JM 08-112
JM 09-37
JM 09-16
JM 09-36
JM 09-15
JM 09-17
G16
JM 08-111
JM 09-14
JM 09-117
JM 08-110
JM 09-13
JM 08-109
JM 08-108
JM 08-107
JM 08-38
JM 08-35
JM 08-34
JM 08-33
JM 08-32
JM 08-30
V8
JM 08-106
JM 08-105
JM 08-103
JM 08-102
JM 10-01 +
JM 11-16 +
JM 11-23
JM 09-76
JM 08-101
JM 08-100
JM 08-99
JM 08-95
JM 09-34
JM 08-94
JM 10-28
JM 10-27
JM 10-26
JM 10-25
V7
JM 08-93
JM 09-33
JM 08-98
JM 08-91
JM 08-96
JM 08-90
JM 08-89
JM 10-52
JM 08-88
JM 08-87
JM 08-86
JM 08-85
JM 10-18
JM 10-17
JM 10-16
G15
G14
G13
G12
G11
G10
JM 08-25
G9
G8
G7
F1
V6
G6
JM 09-23
JM 09-31
JM 09-26
JM 08-84
V5
JM 10-30
JM 10-11
JM 10-12
JM 10-13
JM 10-14
JM 10-15
V4
JM 08-83
JM 08-82
JM 08-81
JM 08-80
G5
JM 08-79
JM 09-116
JM 08-78
JM 08-76
JM 08-75
G4
JM 09-22
JM 10-04
V3
JM 10-03
V2
JM 08-71
JM 08-70
JM 08-23 +
JM 08-28
JM 08-69
JM 08-68
JM 08-67
JM 08-65+
JM 08-22 +
JM 08-29
JM 08-66
JM 10-24
JM 10-23
JM 08-74
V1
G3
JM 08-73
G2
G1
Vb
Va
1
2
3
4
5
6

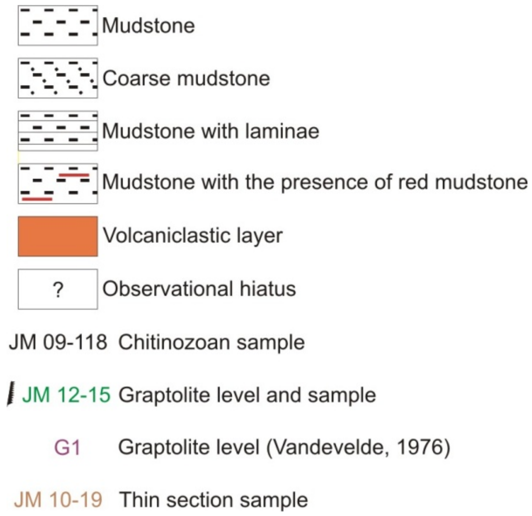


Fig. II.5.3. Litholog of the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville together with a composite litholog of the section. The litholog is given on the previous page; the legend of the litholog is given on this page.

The boundary between the *griestoniensis* and the *crenulata* Biozones coincide, according to Vandevelde (1976), with the first deposits of red shales.

The last outcrop of volcaniclastic rock (volcaniclastic layer V9) is situated in her unit 6 and stratigraphically above G16 with a lower Wenlock age. This means that there was still volcanic activity present in the lower Wenlock of the study area.

Vandevelde (1976) studied in four samples their chitinozoan content. Three of them were however barren. Due to the poor knowledge of the stratigraphic distribution of the chitinozoans at that time, no further information is given by her. Maes (1976) studied the acritarchs in two samples (the same samples as Vandevelde, 1976), mostly doing an systematical inventory of the acritarch content.

A part of the results obtained during the PhD study are presented at national and international conferences (Mortier & Verniers, 2009a, 2009b, 2010; Mortier *et al.*, 2010, 2011a, 2011b).

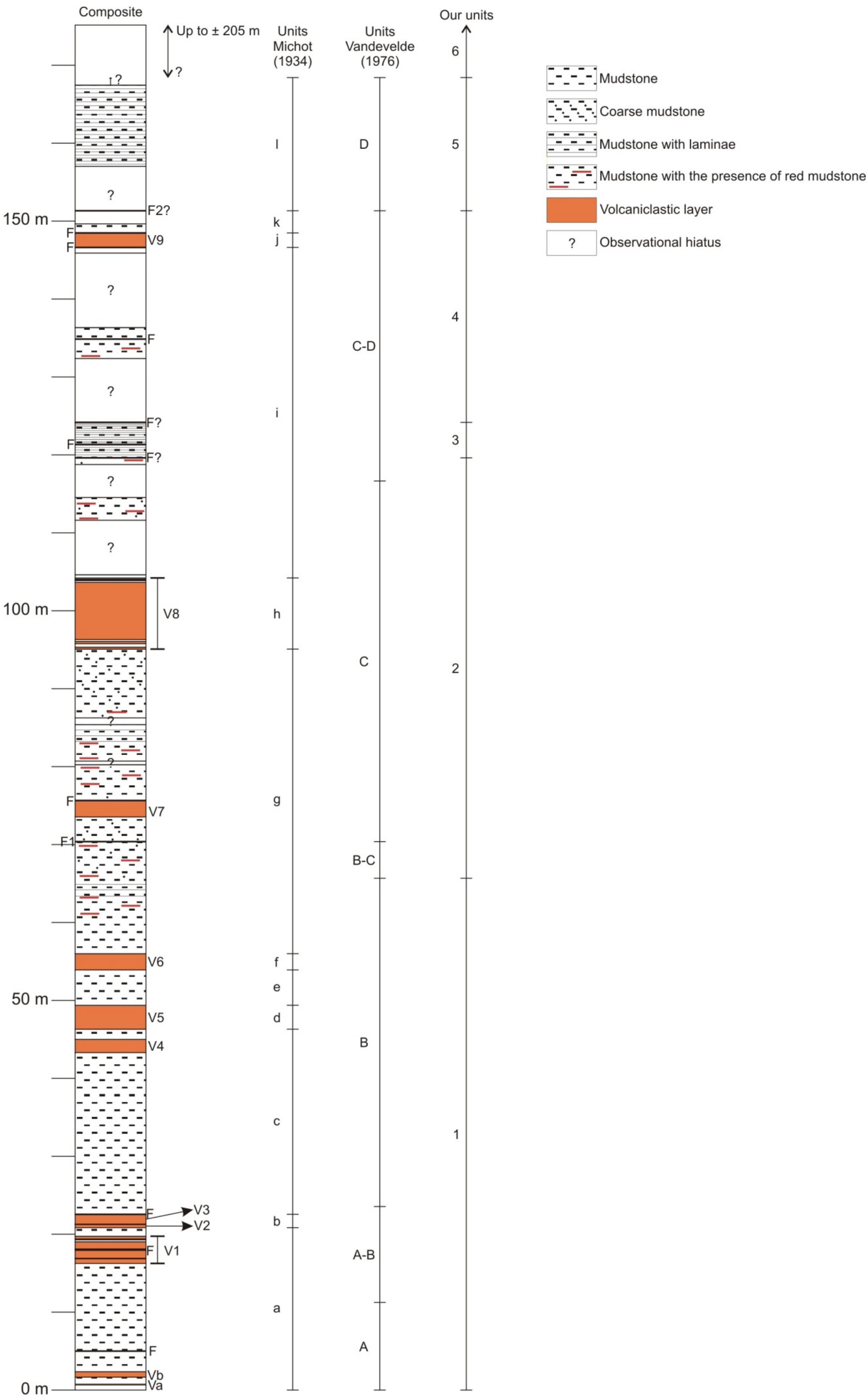
5.3. New data

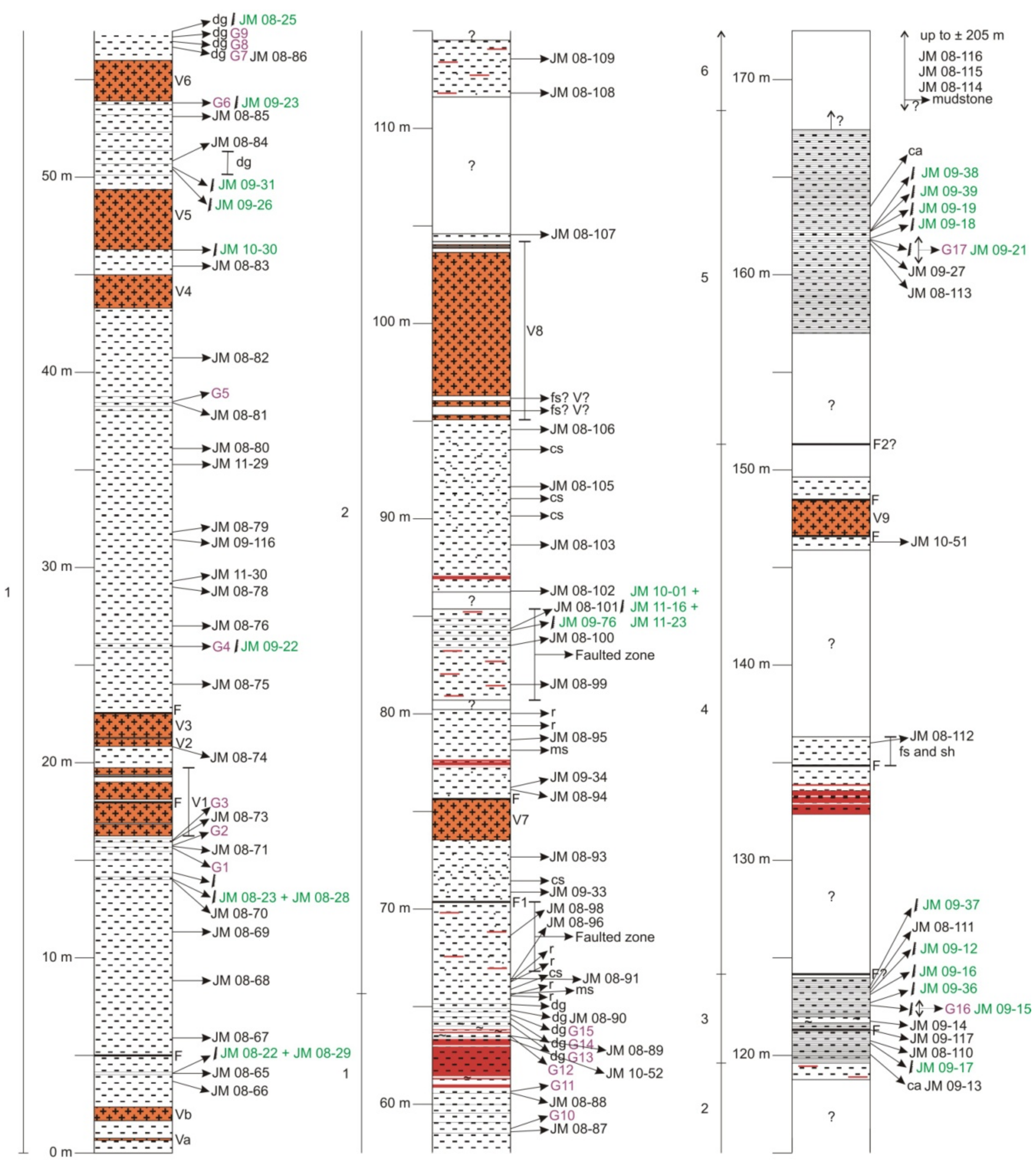
see also fig. II.5.3., fig. II.5.4. and fig. II.5.5

5.3.1. Lithological results

Outcrops are visible mainly on both sides along the brooklet. In the northern part of the section outcrops have been studied along two paths west and east of the brooklet (see fig. II.5.6). A litholog have been constructed and is displayed in fig. II.5.3.

Fig. II.5.4. Next page. Composite litholog of the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville with the correlation of the units of Michot (1934), Vandevelde (1976) and our units.


Composite
Up to ± 205 m
?
Units Michot (1934)
Units Vandevelde (1976)
Our units
150 m
100 m
50 m
0 m
F2?
V9
F
F?
F1
V8
V7
V6
V5
V4
V3
V2
V1
Vb
Va
l
k
j
i
h
g
f
e
d
c
b
a
D
C-D
C
B-C
B
A-B
A
6
5
4
3
2
1
Mudstone
Coarse mudstone
Mudstone with laminae
Mudstone with the presence of red mudstone
Volcaniclastic layer
Observational hiatus



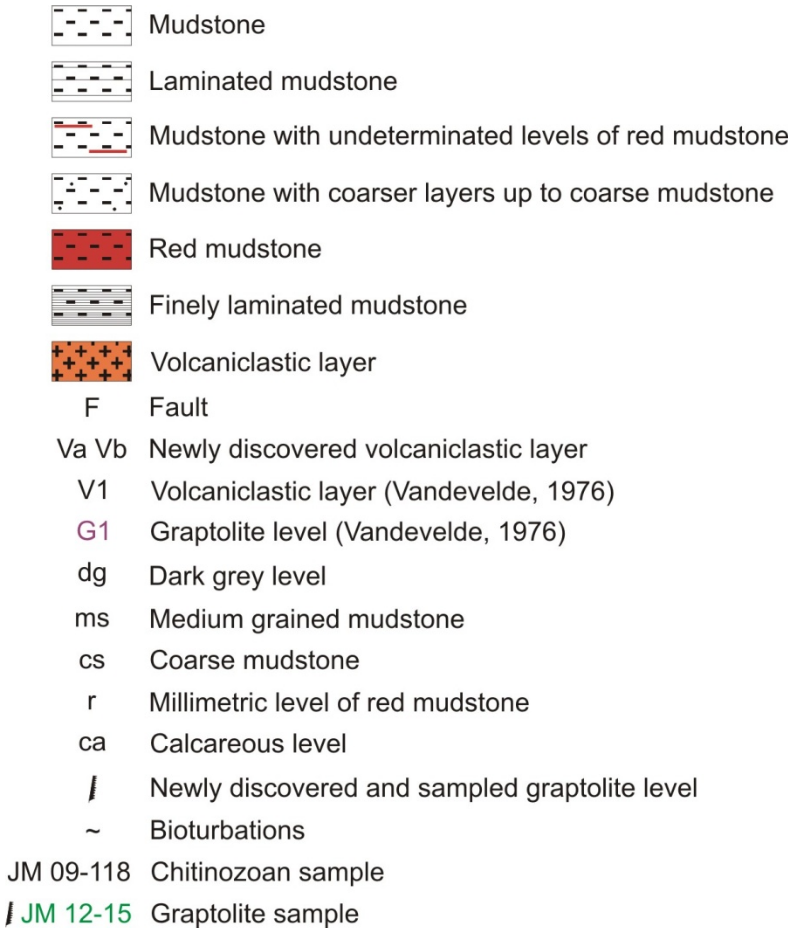


Fig. II.5.5. Detailed composite litholog of the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville.

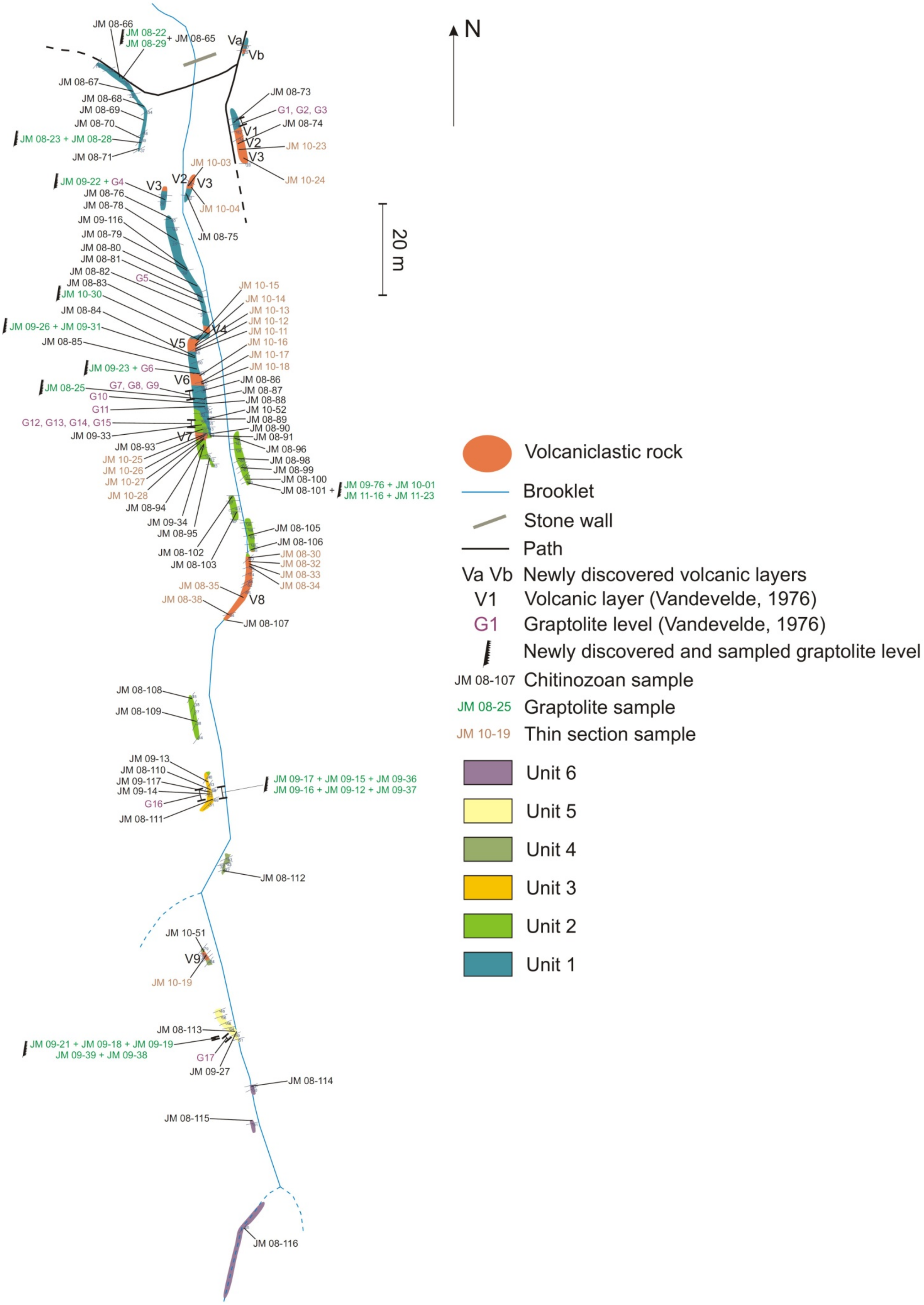

N
20 m
Va
Vb
V1
V2
V3
V4
V5
V6
V7
V8
V9
JM 08-66
JM 08-22
JM 08-29
+ JM 08-65
JM 08-67
JM 08-68
JM 08-69
JM 08-70
JM 08-23 + JM 08-28
JM 08-71
JM 08-73
G1, G2, G3
JM 08-74
JM 10-23
JM 10-24
JM 10-03
JM 09-22 + G4
JM 08-76
JM 08-78
JM 10-04
JM 09-116
JM 08-75
JM 08-79
JM 08-80
JM 08-81
JM 08-82
G5
JM 08-83
JM 10-30
JM 08-84
JM 09-26 + JM 09-31
JM 08-85
JM 10-15
JM 10-14
JM 10-13
JM 10-12
JM 10-11
JM 10-16
JM 10-17
JM 10-18
JM 09-23 + G6
JM 08-25
G7, G8, G9
G10
G11
G12, G13, G14, G15
JM 09-33
JM 08-86
JM 08-87
JM 08-88
JM 10-52
JM 08-89
JM 08-90
JM 08-91
JM 08-93
JM 10-25
JM 10-26
JM 10-27
JM 10-28
JM 08-94
JM 09-34
JM 08-95
JM 08-96
JM 08-98
JM 08-99
JM 08-100
JM 08-101 +
JM 09-76 + JM 10-01
JM 11-16 + JM 11-23
JM 08-102
JM 08-103
JM 08-105
JM 08-106
JM 08-30
JM 08-32
JM 08-33
JM 08-34
JM 08-35
JM 08-38
JM 08-107
JM 08-108
JM 08-109
JM 09-13
JM 08-110
JM 09-117
JM 09-14
G16
JM 08-111
JM 09-17 + JM 09-15 + JM 09-36
JM 09-16 + JM 09-12 + JM 09-37
JM 08-112
JM 10-51
JM 10-19
JM 08-113
JM 09-21 + JM 09-18 + JM 09-19
JM 09-39 + JM 09-38
G17
JM 09-27
JM 08-114
JM 08-115
JM 08-116
Volcaniclastic rock
Brooklet
Stone wall
Path
Va Vb Newly discovered volcanic layers
V1 Volcanic layer (Vandevelde, 1976)
G1 Graptolite level (Vandevelde, 1976)
Newly discovered and sampled graptolite level
JM 08-107 Chitinozoan sample
JM 08-25 Graptolite sample
JM 10-19 Thin section sample
Unit 6
Unit 5
Unit 4
Unit 3
Unit 2
Unit 1

Fig. II.5.6. Previous page. Map of the section Neuville-sous-Huy, ravine 700 m east.

The section can be divided into 6 units going from north to south:

Unit 1: Grey, green-grey to green, compact mudstone alternating with dark grey and green-grey, laminated mudstone. In the laminated dark grey levels graptolites occur and it is only in these levels that they have been found. In the northern part, north of V3 and just south of it, this mudstone is hard and quartzitic. Six layers of red mudstone appear between the graptolite levels G11 and G13 with respectively thicknesses from north to south of 17, 8, 152, 32, 8 and 5 cm. Between the red mudstone levels of 32 cm and 8 cm thick a level of green to grey mudstone occur. But 10 cm above the base a yellowish layer occur of ±2.5 mm thick. This is the only yellowish level that has been observed. Sometimes the laminated part can pass upwards into a compact level of dark grey mudstone and then pass again upwards into a laminated part. The transition to unit 2 is gradual and has been taken at the first level of coarser mudstone. Unit 1 contains eight volcaniclastic layers of which six of them are already defined by Vandevelde, 1976 (V1 to V6) and two new one discovered by us at the northern part of the section (labeled as Va and Vb). The thickness of unit 1 is 65.7 meters.

Fig. II.5.7. On the left green mudstone with a 1 mm thick lamina of red mudstone. On the right red mudstone with a less than 1 mm thick lamina of green mudstone. Both from unit 2.

Unit 2: Green, green-grey to grey and dark grey mudstone intercalated with grey coarser mudstone up to coarse mudstone, sometimes occurring in clear centimetric banks. The green colour is only present in the finer mudstone. Red mudstone occur only in the finer parts of the unit and is millimetric, centimetric to decimetric. Red mudstone laminae in green mudstone do occur that are less than 1 mm thick (see fig. II.5.7). The opposite do also occur with a laminae, less than 1 mm thick, of green mudstone in red mudstone (see fig. II.5.7). There are two levels where coarser mudstones dominate: from 1.1 m to 1.9 m above fault F1 and 4.9 to 0.5 m below the base of V8. These coarser mudstone contain also some very fine sandstone to coarsest mudstone beds. These beds display a normal polarity hence younging of the layers is to the south. This normal polarity has been observed by cross-bedding, incision of coarse mudstone into fine mudstone, a sharp boundary of coarse mudstone with a fining upwards. One level of this unit have been discovered containing graptolites. This level is made up of dark grey, laminated mudstone. It has the same lithology as the graptolite levels of unit 1. Unit 2 contains two volcaniclastic layers, V7 and V8. The thickness is approximately 53.9 meters and the upper ± 15 meters is poorly exposed. The upper boundary is exposed but the type of contact with unit 3 is not clearly caused by weathering.

Unit 3: Dark grey, finely laminated mudstone. These are laminated hemipelagites. They contain graptolites. Some levels are calcareous. One level, 31 cm thick, of green-grey compact mudstone with bioturbations (as dark grey patches orientated parallel with the bedding) is present. One 6 cm thick level of grey compact mudstone somewhat calcareous, is present. The thickness is approximately 4.6 meters but the upper boundary is not exposed and is supposed to be by fault. This assumption is made because the uppermost exposed part of this unit is influenced by faults. Hence we assume the presence of a fault nearby.

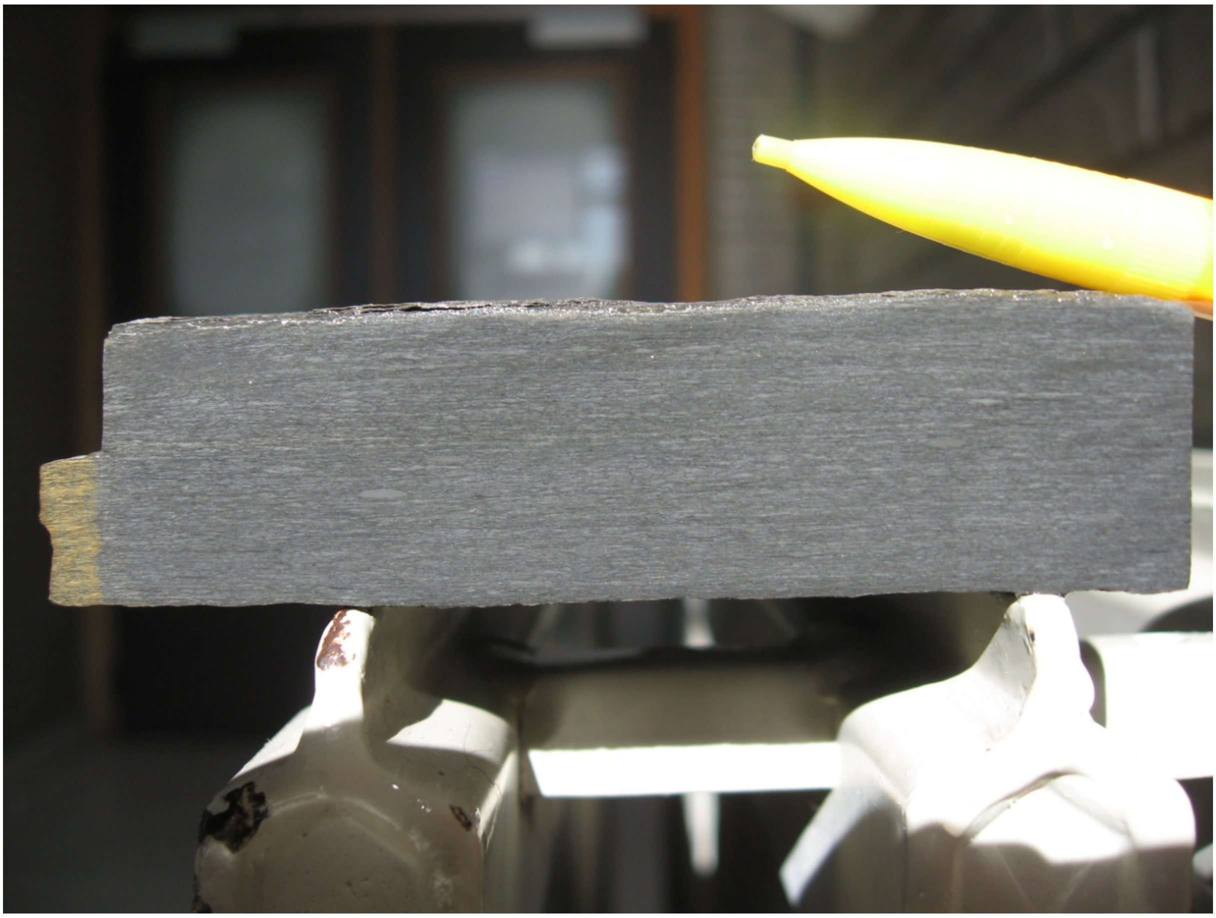


Fig. II.5.8. Laminated hemipelagites of unit 5.

Unit 4: Alternation of red mudstone and green, green-grey to dark grey, sometimes laminated mudstone. Higher up the red mudstone disappear. One volcaniclastic layer is present, V9. The thickness is estimated at 27.2 meters but only 4 meters and 3.8 meters of this unit is exposed. The upper boundary is not exposed and not seen by us but it is supposed to be by fault, because Michot (1932a, 1934), Vandevelde (1976) and Maes *et al.* (1978) observed a fault at this place. But a normal stratigraphical contact cannot be excluded.

Unit 5: Dark grey, finely laminated mudstone. These are laminated hemipelagites (see fig. II.5.8). They contain graptolites and possible fragments of Conularia are found. At one level we found the presence of calcite flakes. This level has been found in the bedding of the brooklet and further examination of this level was not possible. Unit 5 is similar in facies to unit 3. The thickness is estimated at 17.1 meters and only 10.4 meters is exposed. The upper boundary is not exposed and its nature is unknown.

Unit 6: Olive green mudstone, only present in three small outcrops. The relationship between these outcrops is unclear. When we group these outcrops together, because of the very similar lithology, the thickness should be approximately 37 meters.

The units 1, 2 and 4 can be included in the newly defined Neuville-sous-Huy Formation. Units 3 and 5 are included in the Naninne Formation. Unit 6 belongs to an unknown formation. A repetition of the facies of the Neuville-sous-Huy Formation is present in the section as unit 4. To explain this we assume the presence of faults on the base and the top of unit 4. But the poor nature of the outcrops (starting from the uppermost part of unit 2) makes it difficult to confirm this assumption.

5.3.2. Tectonic deformation

The outcrops do not show much faulting and disturbance of the bedding. The faults that are observed are always dipping to the south, inverse and two types occur. The subvertical faults with a centimetric, decimetric to metric displacement and the weakly dipping faults where the displacement could not be quantified. An example of a weakly south dipping fault can be found in outcrop W12 (see fig. II.5.1) indicated as fault F1 in fig. II.5.3, II.5.4 and II.5.5.

5.3.3. Chitinozoan results

see also fig. II.5.9. and fig. II.5.10.

We extracted and studied 3812 studied chitinozoans in a total of 56 samples (see table II.5.2). Four samples, of which one is from a red mudstone level (JM 10-52), are barren. The chitinozoans are poorly to moderately well preserved, which can vary largely from sample to sample. But we can say that starting from sample JM 08-108 (in the upper part of unit 2) and the samples above it the chitinozoans are in most cases poorly preserved. Except for the three uppermost samples in unit 6 (JM 08-114, JM 08-115 and JM 08-116) where the preservation is a slightly better. The preservation of the chitinozoans in unit 1 is better in comparison with unit 2 the covering unit.

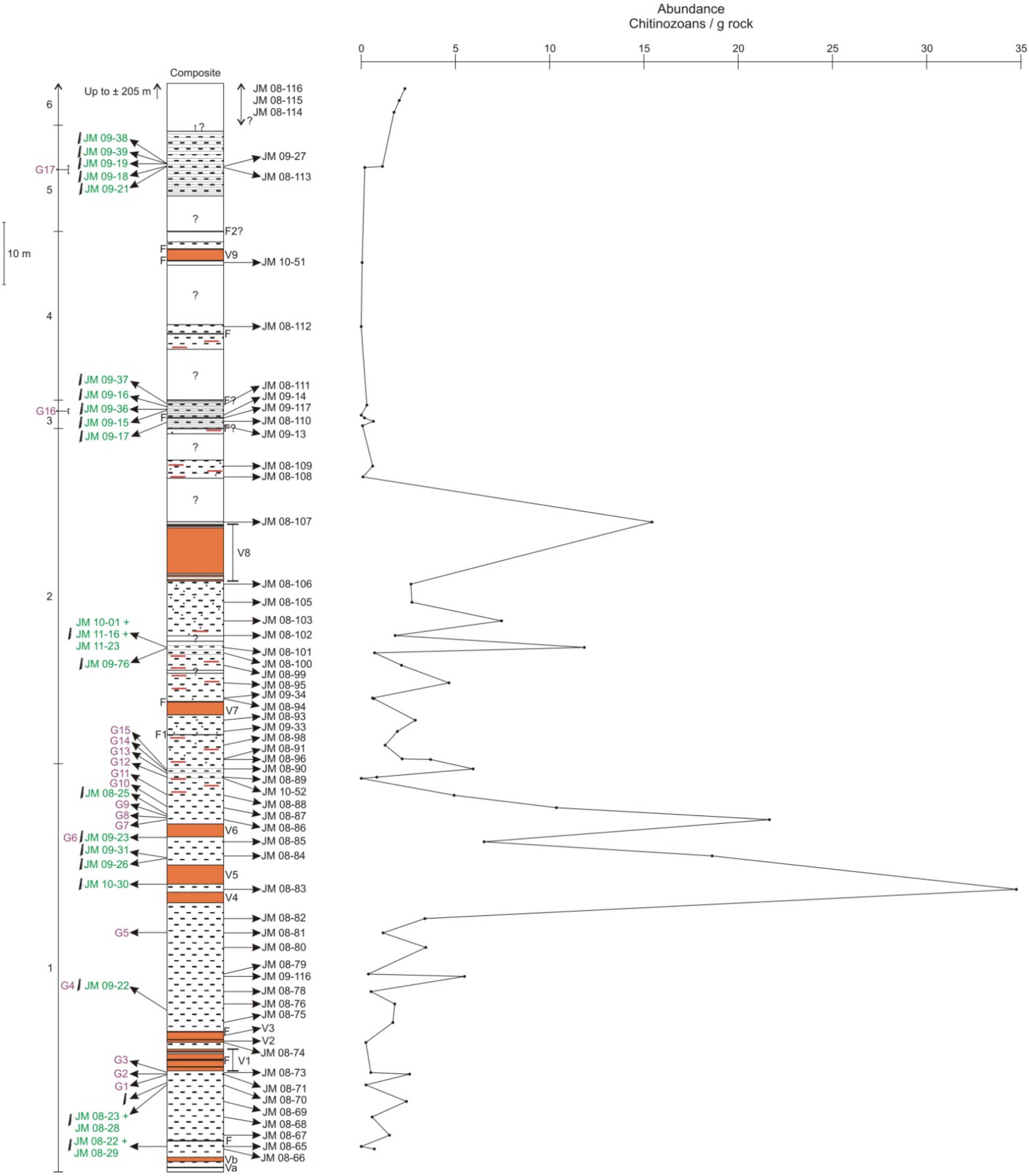
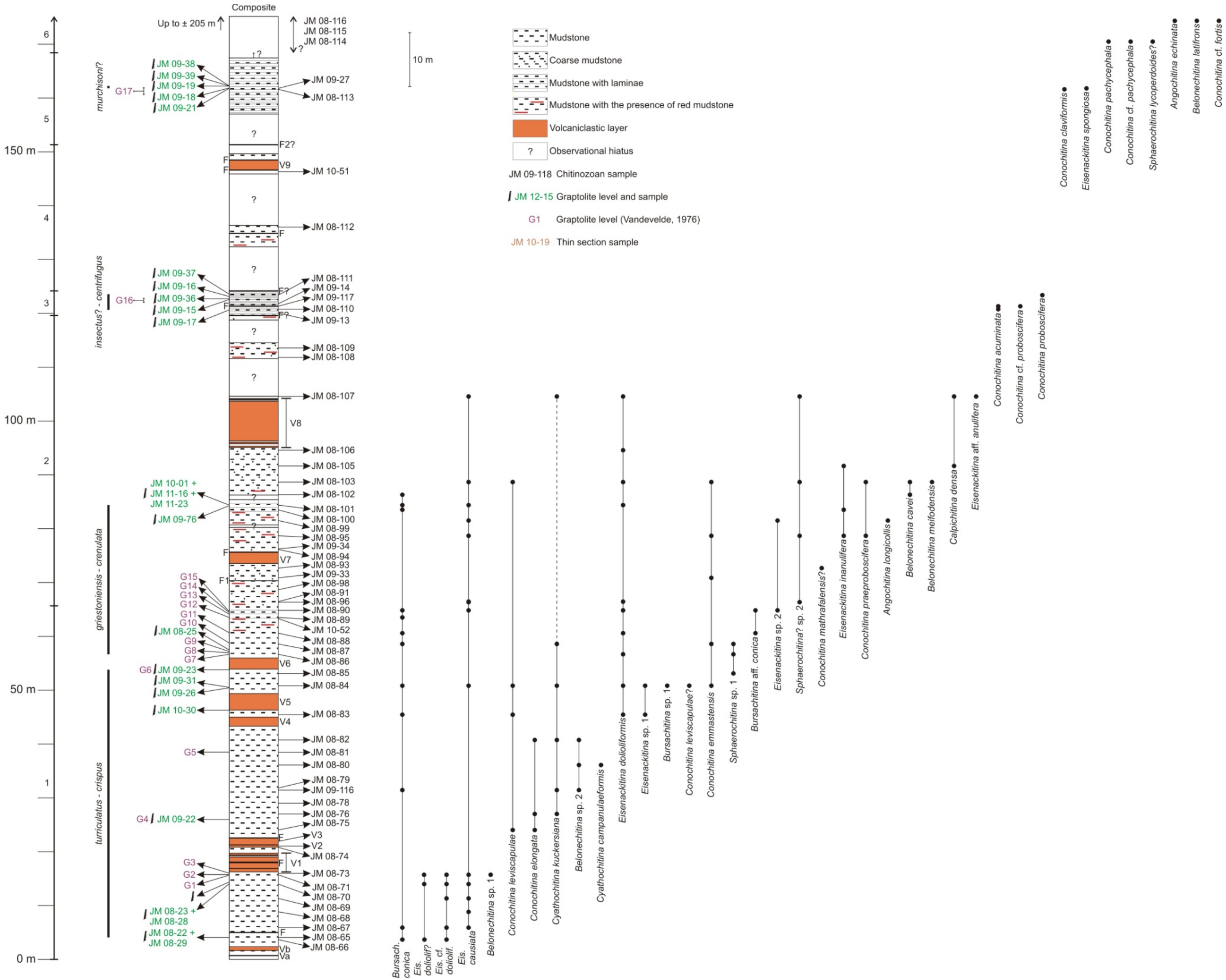


Fig. II.5.9. Composite litholog of the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville with a graph of the chitinozoan abundance throughout the section. The legend is the same as in fig. II.5.3



Composite
Up to ± 205 m
JM 08-116
JM 08-115
JM 08-114
10 m
0 m
50 m
100 m
150 m
1
2
3
4
5
6
murchisoni?
insectus? - centrifugus
griestoniensis - crenulata
turriculatus - crispus
G17
G16
JM 09-38
JM 09-39
JM 09-19
JM 09-18
JM 09-21
JM 09-27
JM 08-113
F2?
V9
JM 10-51
JM 08-112
JM 09-37
JM 09-16
JM 09-36
JM 09-15
JM 09-17
JM 08-111
JM 09-14
JM 09-117
JM 08-110
JM 09-13
JM 08-109
JM 08-108
JM 08-107
V8
JM 08-106
JM 08-105
JM 08-103
JM 08-102
JM 10-01 +
JM 11-16 +
JM 11-23
JM 09-76
JM 08-101
JM 08-100
JM 08-99
JM 08-95
JM 09-34
JM 08-94
V7
JM 08-93
JM 09-33
JM 08-98
JM 08-91
JM 08-96
JM 08-90
JM 08-89
JM 10-52
JM 08-88
JM 08-87
JM 08-86
V6
F1
G15
G14
G13
G12
G11
G10
JM 08-25
G9
G8
G7
G6
JM 09-23
JM 09-31
JM 09-26
JM 10-30
JM 08-85
JM 08-84
V5
V4
JM 08-83
JM 08-82
G5
JM 08-81
JM 08-80
JM 08-79
JM 09-116
JM 08-78
G4
JM 09-22
JM 08-76
JM 08-75
V3
V2
JM 08-74
V1
G3
G2
G1
JM 08-73
JM 08-71
JM 08-70
JM 08-69
JM 08-68
JM 08-23 +
JM 08-28
JM 08-22 +
JM 08-29
JM 08-67
JM 08-65
JM 08-66
Vb
Va
Mudstone
Coarse mudstone
Mudstone with laminae
Mudstone with the presence of red mudstone
Volcaniclastic layer
Observational hiatus
JM 09-118 Chitinozoan sample
JM 12-15 Graptolite level and sample
G1 Graptolite level (Vandevelde, 1976)
JM 10-19 Thin section sample
Bursach. conica
Eis. dolioli?
Eis. cf. doliolif.
Eis. causiata
Belonechitina sp. 1
Conochitina leviscapulae
Conochitina elongata
Cyathochitina kuckersiana
Belonechitina sp. 2
Cyathochitina campanulaeformis
Eisenackitina dolioliformis
Eisenackitina sp. 1
Bursachitina sp. 1
Conochitina leviscapulae?
Conochitina emmastensis
Sphaerochitina sp. 1
Bursachitina aff. conica
Eisenackitina sp. 2
Sphaerochitina? sp. 2
Conochitina mathrafalensis?
Eisenackitina inanulifera
Conochitina praeproboscifera
Angochitina longicollis
Belonechitina cavei
Belonechitina meifodensis
Calpichitina densa
Eisenackitina aff. anulifera
Conochitina acuminata
Conochitina cf. proboscifera
Conochitina proboscifera
Conochitina claviformis
Eisenackitina spongiosa
Conochitina pachycephala
Conochitina cf. pachycephala
Sphaerochitina lycoperdoides?
Angochitina echinata
Belonechitina latifrons
Conochitina cf. fortis

Fig. II.5.10. Previous page. Composite litholog of the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville with the distribution of the chitinozoans throughout the section together with the graptolite biozonation.

The abundance of the chitinozoans varies through the section (see fig. II.5.9), although some trends are visible. From sample JM 08-66 (at the base of unit 1) to JM 08-82 (middle part unit 1) the abundance is varying from nihil to a maximum of 3.43 chitinozoans per gram of rock in JM 08-80 (except sample JM 09-116 where the abundance is even higher 5.48 chitinozoans per gram). In the following sample, JM 08-83, and following samples, until sample JM 08-90 (middle to upper part unit 1), a lot of higher values are attained from almost more to 5 chitinozoans per gram of rock (with a maximum of 34.76 chitinozoans per gram of rock in sample JM 08-83 the highest value of the whole section). Further upwards (starting in unit 2) the abundance is lowering to a minimum in sample JM 09-34 (lower part unit 2) with 0.60 chitinozoans per gram of rock. In the following samples (from sample JM 08-95 until JM 08-107; middle part unit 2) the chitinozoan abundance is increasing with a maximum in JM 08-107 of 15.43 chitinozoans per gram of rock but low values still occur. The higher samples, starting from JM 08-108 until JM 09-27 (upper part unit 2, unit 3, 4 and 5), contain almost always less than 1 chitinozoan per gram rock, with as exception JM 09-27 with 1.13 chitinozoans per gram of rock. In the uppermost three samples (from sample JM 08-114 until JM 08-116), occurring in small outcrops, the chitinozoan abundance is slightly higher, around 2 chitinozoans per gram of rock, with a maximum value of 2.32 chitinozoans per gram of rock for sample JM 08-116.
The rocks are almost always quite weathered in the outcrop of JM 08-108 and further southwards (the outcrops become small, discontinuously and weathering is present). The sample JM 09-27 has been taken at the level of the brooklet where the rock was still fresh and weathering has almost not occurred. This is probably the reason for the better abundance.

Bursachitina conica and *Eisenackitina causiata* range through almost whole unit 1 and unit 2. In the lowermost part specimens of *Eisenackitina dolioliformis*? and *Eisenackitina* cf. *dolioliformis* occur. Typical specimens of *Eisenackitina dolioliformis* start to occur from JM 08-83. In between *Conochitina leviscapulae* (also higher), *Conochitina elongata* and *Cyathochitina kuckersiana* occur. *Conochitina emmastensis* starts to occur in the following sample JM 08-84. Remarkably is the dominance of the genus *Ancyrochitina* spp. in the samples JM 08-85 to sample JM 08-89 up to almost 82 % of the total chitinozoan content in sample JM 08-87. In the lowermost sample of unit 2 (JM 08-96) *Lagenochitina*? sp. 2 starts to occur together with species from the underlying unit. From sample JM 08-95 up to sample JM 08-107 there are scattered occurrences of *Eisenackitina inanulifera*, *Conochitina praeproboscifera*, *Angochitina longicollis*, *Belonechitina cavei*, *Belonechitina meifodensis* and *Calpichitina densa* together with scattered occurrences of *Bursachitina conica*, *Eisenackitina causiata*, *Eisenackitina dolioliformis*, *Conochitina emmastensis* and *Conochitina leviscapulae* from below.

Unit	Sample number	*Cyathochitina* spp.	*Bursachitina conica*	*Eisenackitina* cf. *dolioliformis*	*Eisenackitina dolioliformis*?	*Belonechitina* spp.	*Conochitina* spp.	*Ramochitina* spp.	*Eisenackitina* spp.	*Eisenackitina causiata*	*Bursachitina* spp.	*Belonechitina* sp. 1	*Ancyrochitina* spp.	*Sphaerochitina* spp.	*Angochitina* spp.	*Fungochitina* spp.	*Conochitina leviscapulae*	*Spinachitina* spp.	*Conochitina elongata*	*Calpichitina* spp.	*Cyathochitina kuckersiana*	*Belonechitina* sp. 2	*Desmochitina* spp.	*Tanuchitina* spp.	*Cyathochitina campanulaeformis*	*Eisenackitina dolioliformis*	*Eisenackitina* sp. 1	*Bursachitina* sp. 1	*Conochitina*? *leviscapulae*?	*Conochitina emmastensis*
6	JM 08-116					2	7		1				5		1															
	JM 08-115												16																	
	JM 08-114	1				5	3		1				3																	
5	JM 09-27					1	2						5	6																
	JM 08-113																													
4	JM 10-51																			1										
	JM 08-112																													
3	JM 08-111						1																							
	JM 09-14																													
	JM 09-117													6																
	JM 08-110						1																							
	JM 09-13																													
2	JM 08-109					1																								
	JM 08-108												1																	
	JM 08-107	6				30	56		3	1			20	1	3			17			4					1				
	JM 08-106					4	5		2				2		1			2		3			1			1				
	JM 08-105					1	10																3							
	JM 08-103					22	27		3	2	1		51		10		1	3					1			1				1
	JM 08-102		1				1				1		5		1															
	JM 08-101		60				3		1	3	10		7		1			1								1				
	JM 08-100		2			2							1																	
	JM 08-99					6	1	1		2			4		2															
	JM 08-95					13	23		4	2			17	2		3		3												1
	JM 09-34						6																							
	JM 08-94					1	2																							
	JM 08-93					3	15						5					2												
	JM 09-33					3	18		2		1		1					1					1							1
	JM 08-98	1				2	4																							
	JM 08-91					2	4		1	2			3			1		1					1			2				
	JM 08-96	3				20	21	1	1	1	1		4	2	1			5												
1	JM 08-90		5			22	2		6	3	13		7													8				
	JM 08-89		5			1	1		1				2																	
	JM 10-52																													
	JM 08-88		5								1		50													1				
	JM 08-87		1				2	1					296	5	1						10									2
	JM 08-86					2	1				1		265	14												1				
	JM 08-85												74	9																
	JM 08-84		14				26		25	10	18		1				6				1					68	1	30	7	2
	JM 08-83		2			2	3		15		1						1									125	39			
	JM 08-82	1				3	13						6	3					1		1	1								
	JM 08-81					3	1				1		7					1	1											
	JM 08-80	3				1	10		4													2	1	1	1					
	JM 08-79					1																								
	JM 09-116		1			11	18		4		2		12	3	2			3			1	2	3							
	JM 08-78					2	1													1										
	JM 08-76					3	8		1				1	2	1			1	2	2	1									
	JM 08-75	1				1	2		1				5			1	2	1	1											
	JM 08-74					1										1														
	JM 08-73						1								2	3														

Sample number	*Sphaerochitina* sp. 1	*Bursachitina* aff. *conica*	*Eisenackitina* sp. 2	*Rhabdochitina* spp.	*Lagenochitina* sp. 1	*Conochirina mathrafalensis*?	*Eisenackitina inanulifera*	*Conochitina praeproboscifera*	*Angochitina longicollis*	*Belonechitina cavei*	*Belonechitina meifodensis*	*Calpichitina densa*	*Eisenackitina* aff. *anulifera*	*Conochitina acuminata*	*Conochitina* cf. *proboscifera*	*Conochitina proboscifera*	*Conochitina claviformis*	*Eisenackitina spongiosa*	*Conochitina* cf. *pachycephala*	*Conochitina pachycephala*	*Sphaerochitina lycoperdoides*?	*Angochitina echinata*	*Conochitina* cf. *fortis*	*Belonechitina latifrons*	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
JM 08-116																						1	1	1	32	51	22.02	2.32
JM 08-115																									27	43	21.28	2.02
JM 08-114																			1	1	1				22	38	21.90	1.74
JM 09-27																		29							34	77	68.15	1.13
JM 08-113																	1								5	6	31.48	0.19
JM 10-51																									1	2	38.86	0.05
JM 08-112																										0	31.50	0.00
JM 08-111																1									7	9	30.18	0.30
JM 09-14																										0	30.55	0.00
JM 09-117														1	2										6	15	82.89	0.18
JM 08-110														1											17	19	29.45	0.65
JM 09-13																									2	2	30.12	0.07
JM 08-109																									19	20	32.78	0.61
JM 08-108																									1	2	21.64	0.09
JM 08-107					12							1	1												161	317	20.55	15.43
JM 08-106																									34	55	20.85	2.64
JM 08-105							2					1													42	59	21.90	2.69
JM 08-103					2			2		1	1														127	256	34.34	7.45
JM 08-102										1															28	38	21.07	1.80
JM 08-101																									50	137	11.57	11.84
JM 08-100							1																		9	15	21.16	0.71
JM 08-99			2						2																25	45	21.00	2.14
JM 08-95					1		1	2																	89	161	34.52	4.66
JM 09-34																									13	19	31.75	0.60
JM 08-94																									12	15	21.90	0.68
JM 08-93						1																			33	59	20.54	2.87
JM 09-33																									33	61	31.83	1.92
JM 08-98																									20	27	21.34	1.27
JM 08-91				1																					28	46	21.21	2.17
JM 08-96					2																				53	115	31.29	3.68
JM 08-90		26	24																						94	210	35.38	5.94
JM 08-89																									7	17	20.52	0.83
JM 10-52																										0	24.28	0.00
JM 08-88		1																							16	74	15.00	4.93
JM 08-87	1																								42	361	34.84	10.36
JM 08-86	2																								45	331	15.28	21.66
JM 08-85	2																								16	101	15.48	6.52
JM 08-84																									83	292	15.68	18.62
JM 08-83																									25	213	15.19	14.02
JM 08-82																									23	52	15.40	3.38
JM 08-81																									4	18	15.58	1.16
JM 08-80																									29	52	15.16	3.43
JM 08-79																									7	8	21.22	0.38
JM 09-116																									31	93	16.96	5.48
JM 08-78																									7	11	21.21	0.52
JM 08-76																									32	54	30.36	1.78
JM 08-75																									11	26	15.49	1.68
JM 08-74																									2	4	15.79	0.25
JM 08-73																									2	8	15.61	0.51

JM 08-71			3	8	7	9		15	4		19	4	2														
JM 08-70			1	1					1																		
JM 08-69			6		2	5		3	11	1																	
JM 08-68						3	1		1	1																	
JM 08-67		2	8					1	5																		
JM 08-65																											
JM 08-66	1	1	1	1	1	1	1	1																			
Total	17	99	19	10	181	317	5	96	48	53	19	880	55	26	9	10	41	5	7	18	5	11	1	1	209	40	30

JM 08-71																											19	90	34.99	2.57
JM 08-70																											1	4	15.91	0.25
JM 08-69																											9	37	15.42	2.40
JM 08-68																											6	12	20.79	0.58
JM 08-67																											8	24	16.02	1.50
JM 08-65																												0	31.54	0.00
JM 08-66																											3	11	15.63	0.70
Total	7	7	5	27	26	1	17	1	4	4	2	2	1	2	1	2	2	1	1	29	1	1	1	1	1	1	1452	3812	1404.35	2.71

Table II.5.2. Chitinozoan results of Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville. Note that sample JM 10-52 comes from a red mudstone level. In sample JM 08-83 approximately 40 % has been fully identified. The other approximately 60 % have a total of 315 chitinozoans. Giving a total of 528 chitinozoans and hence 34.76 chitinozoans per gram of rock for this sample.

Amongst the few chitinozoans in unit 3 *Conochitina acuminata* and *Conochitina proboscifera* occur. Many of them can only be identified as just chitinozoan species.

Only two chitinozoans have been found in the two samples (JM 08-112 and JM 10-51) taken from unit 4. Only one specimen can be attributed to the genus level as *Calpichitina* sp.

Two samples have been dissolved from unit 5 (JM 08-113 and JM 09-27). They contain *Conochitina claviformis* and *Eisenackitina spongiosa*.

From unit 6 only small and discontinuous outcrops are present. We will handle the chitinozoan results separately because we don't know the relationships between every outcrop (except the same lithology). In sample JM 08-114 *Conochitina pachycephala* and *Sphaerochitina lycoperdoides*? occur. In sample JM 08-115 *Ancyrochitina* spp. are present together with no further identifiable chitinozoans. In sample JM 08-116 *Angochitina echinata*, *Belonechitina latifrons* and *Conochitina* cf. *fortis* is found.

Systematics of the chitinozoans

Incertae sedis group Chitinozoa Eisenack, 1931

Order Prosomatifera Eisenack, 1972

Family Conochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Conochitinae Paris, 1981

Genus *Conochitina* Eisenack, 1931 emend. Paris *et al.*, 1999

Conochitina cf. *fortis*

Plate II.5.10., specimen 12

Material: 1 specimen from JM 08-116 (unit 6).

Dimensions: L: 250 µm (n=1); Dp: 112 µm (n=1); Dc: 59 µm (n=1).

Description: we refer for the description to Nestor, 1982a & 1994.

Discussion: The specimen is too conical. The mucron does not show concentric striation.

Conochitina? *leviscapulae*?

Plate II.5.6., specimens 13-15

Material: 7 specimens from JM 08-84 (unit 1).

Dimensions: L: 170-205-272 µm (n=6); Dp: 98-119-150 µm (n=6); Dc: 58-68-90 µm (n=7).

Description: we refer for the description to Mullins & Loydell, 2001.

Discussion: Our specimens differ in having a rounded basal margin and a neck that slightly widens to the aperture. The presence of the flexure is more pronounced (but not always) but the location of the shoulders is still not easy to locate. Hence the questioning to include these specimens in the genus of *Conochitina*.

Conochitina mathrafalensis?

Plate II.5.8., specimen 11

Material:1 specimen from JM 08-93 (unit 2).

Dimensions: L: ≥220 µm (n=1); Dp: 90 µm (n=1); Dc: 50 µm (n=1).

Description: we refer for the description to Mullins & Loydell, 2001.

Discussion: The specimen is too small to belong to *Conochitina mathrafalensis*.

Conochitina cf. *pachycephala*

Plate II.5.10., specimen 6

Material: 1 specimen from JM 08-114 (unit 6).

Dimensions: L: >320 µm (n=1); Dp: 94 µm (n=1); Dc: 55 µm (n=1).

Description: we refer for the description to Eisenack, 1964 and additional description to Nestor, 1994

Discussion: The specimen shows some deformation at the base. The specimen has a claviform chamber excluding the specimen to be *Conochitina pachycephala*.

Conochitina cf. *proboscifera*

Plate II.5.9., specimen 13

Material: 2 specimens from JM 09-117 (unit 3).

Dimensions: L: >170 - >298 µm (n=2); Dp: 70-82 µm (n=2); Dc: 55 µm (n=1).

Description: we refer for the description to Eisenack, 1937 and additional description to Nestor, 1994.

Discussion: The two specimens narrow too much passing into the aperture to be included in *Conochitina proboscifera*. The maximal width is slightly too low and the mucron is small.

Subfamily Belonechitininae Paris, 1981

Genus *Belonechitina* Jansonius, 1964

Belonechitina sp. 1

Plate II.5.3., specimens 3, 4

Material: 19 specimens from JM 08-71 (unit 1).

Dimensions: L: 210-255-300 µm (n=4); Dp: 89-100-120 µm (n=4); Dc: 48-61-80 µm (n=5).

Description: The species is thick walled. The base is flat to convex with a rounded basal edge. The chamber is subcylindrical to slightly ovoid. No flexure, shoulders and neck can be observed. It is very densely ornamented with tubercules to granules, decreasing in size quickly towards the aperture, where a felt-like ornamentation is present.

Discussion: Although deformation is present on many species, the species can easily be identified by its thick wall and the type of ornamentation. The species can be best compared with *Belonechitina postrobusta* (Nestor, 1980b) but our species can have a convex base whilst *Belonechitina postrobusta* has a flat base that can be concave in the central part. *Belonechitina* sp.1 has a very dense ornamentation never occurring in *Belonechitina postrobusta*. *Belonechitina meifodensis* (Mullins & Loydell, 2001) narrows too much towards the aperture. The L/Dp ratio of *Eisenackitina dolioliformis* (Umnova, 1976) is lower and the ornamentation of tubercules and granules are placed separately (although they can touch each other but never too much).

Belonechitina sp. 2

Plate II.5.3., specimens 14-16

Material: 2 broken specimens from JM 09-116 (unit 1), 2 specimens (1 complete, 1 broken) from JM 08-80 (unit 1), 1 broken specimen from JM 08-82 (unit 1).

Dimensions: L: 230 µm (n=1); Dp: 61-69-75 µm (n=5); Dc: 41-49-57 µm (n=5).

Description: The species has a flat to slightly convex base and a bluntly rounded basal edge. The chamber narrows straight to slightly convex and the neck widens slightly towards the aperture. The position of the flexure is hard to determine. Nevertheless the length of the neck is approximately 3/5 of the total length of the vesicle. The ornamentation is best developed at the base and consists of densely placed, thick and short spines (almost grana). They become less prominent towards the aperture and decrease in size very quickly.

Discussion: Although only 1 complete specimen has been recovered (in the other 4 specimens the neck is broken), the species has a characteristic outline and ornamentation. *Belonechitina* *cavei* (Mullins & Loydell, 2001) has generally no flexure and a smaller ornamentation. *Belonechitina meifodensis* (Mullins & Loydell, 2001) has a larger maximal width and a spongy ornament, not present in our species.

Family Lagenochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Lagenochitininae Paris, 1981

Genus *Lagenochitina* Eisenack, 1931 emend. Paris *et al.*, 1999

Lagenochitina sp. 1

Plate II.5.8., specimens 5-9

Material: 2 specimens from JM 08-96 (unit 2), 1 specimen from JM 08-95 (unit 2), 2 specimens from JM 08-103 (unit 2), 12 specimens from JM 08-107 (unit 2).

Dimensions: L: 188-209-228 µm (n=4); Dp: 68-101-135 µm (n=15); Dc: 29-38-50 µm (n=4).

Description: The species has a slighty convex to convex base passing into an ovoid chamber. The chamber is followed by a neck varying in width. The flexure is in most cases hard to distinguish. The vesicle is ornamented with very densely placed, little granules.

Discussion: The neck is in many cases broken. But the species has a very characteristic form and ornamentation that makes the species easily recognizable. The ornamentation of the species never reaches enough length to include the species into the genus *Angochitina*. The presence of a neck exclude the species to be included into the genus *Eisenackitina*.

Genus *Sphaerochitina* Eisenack, 1955a emend. Paris *et al.*, 1999

Sphaerochitina lycoperdoides?

Plate II.5.10., specimen 8

Material: 1 specimen from JM 08-114 (unit 6).

Dimensions: L: 145 µm (n=1); Dp: 78 µm (n=1); Dc: 26 µm (n=1).

Description: we refer for the description to Laufeld, 1974.

Discussion: The specimen is larger than described by Laufeld, 1974. Hence the use of open nomenclature.

Sphaerochitina sp. 1

Plate II.5.7., specimens 5-7

Material: 2 specimens from JM 08-85 (unit 1), 2 specimens from JM 08-86 (unit 1), 1 specimen from JM 08-87 (unit 1).

Dimensions: L: 160-178-195 µm (n=3); Dp: 65-71-75 µm (n=5); Dc: 29-30-32 µm (n=5).

Description: The species has a conical-ovoid chamber passing into a neck slightly widening to the aperture. The chamber is curved and the vesicle wall is rugose and ornamented with granules. The base is convex having no basal margin. The maximal width is at or near the base.

Discussion: The species is easily recognizable by the curved chamber.

Order Operculatifera Eisenack, 1931

Family Desmochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Desmochitininae Paris, 1981

Genus *Bursachitina* Taugourdeau, 1966 restrict. Paris, 1981

Bursachitina aff. *conica*

Plate II.5.7., specimens 10-12

Material: 1 specimen from JM 08-88 (unit 1), 26 specimens from JM 08-90 (unit 1).

Dimensions: L: 213-283-328 µm (n=17); Dp: 120-153-190 µm (n=17); Dc: 72-94-125 µm (n=21).

Description: The species has a sharp to rounded basal margin and a flat base. The flanks of the chamber are convex. The chamber goes over into a neck with a clear to unclear flexure. The neck is subcylindrical, variable in length but reaches always a considerable length.. The vesicle wall is smooth.

Discussion: This species is distinguished from *Bursachitina conica* (Mullins & Loydell, 2001) by the presence of a neck and flexure. When the neck is broken it is difficult to see the difference between the two species. Specimens are present with characteristics of *Bursachitina conica* where the flexure is not so clear. But in these specimens the neck always reaches a considerable length and hence have been placed in *Bursachitina* aff. *conica*. The presence of an operculum justifies the assignment to the genus *Bursachitina* (Paris *et al.*, 1999) although a neck is present.

Bursachitina sp. 1

Plate II.5.6., specimens 5-12

Material: 29 specimens from JM 08-84 (unit 1).

Dimensions: L: 151-178-221 µm (n=23); Dp: 81-95-112 µm (n=28); Dc: 48-58-69 µm (n=16).

Description: a species with a flat to slightly convex or concave base and broadly to sharply rounded basal edge. The chamber is ovoid with the maximal diameter present in the first half of the chamber or around halfway up the length of the chamber. The chamber goes over into the neck, with an unclear flexure, slightly narrowing to the aperture. It is possible to distinguish the chamber and the neck but it is not so pronounced.

Discussion: The species can be confused with *Bursachitina conica* (Mullins & Loydell, 2001) but *Bursachitina conica* has generally no flexure (or rare) and if present it is situated close to the aperture. *Bursachitina* sp. 1 has an unclear flexure, situated lower down of the aperture. *Bursachitina conica* and *Bursachitina* aff. *conica* has a thicker wall than Bursachitina sp.1. The presence of an operculum justifies the assignment to the genus *Bursachitina* (Paris *et al.*, 1999) although a neck is present.

Subfamily Eisenackitininae Paris, 1981

Genus *Eisenackitina* Jansonius, 1964 restrict. Paris, 1981

Eisenackitina aff. *anulifera*

Plate II.5.9., specimen 4

Material: 1 specimen from JM 08-107 (unit 2).

Dimensions: L: 111 µm (n=1); Dp: 69 µm (n=1); Dc: 37 µm (n=1).

Description: The chitinozoan has a convex base and bluntly rounded basal edge. The flanks of the vesicle are at the lowermost base subcylindrical going into straight flanks narrowing upwards. It passes into a subcylindrical neck. There are no shoulders present but a flexure is visible. The vesicle wall bears a felt-like to rugose ornamentation.

Discussion: Our specimen does not possess the typical ring-like thickening of *Eisenackitina anulifera* (Verniers, 1999) and no shoulders are present. Hence the use of open nomenclature.

Eisenackitina dolioliformis?

Plate II.5.2., specimens 2, 3

Material: 1 specimen from JM 08-66 (unit 1), 1 specimen from JM 08-70 (unit 1), 8 specimens from JM 08-71 (unit 1).

Dimensions: L: 159-180-215 µm (n=7); Dp: 95-124-170 µm (n=6); Dc: 55 µm (n=1).

Description: we refer for the description to Umnova, 1976 and additional description to Nestor, 1994.

Discussion: The vesicle has the typical form and dimensions of *Eisenackitina dolioliformis* (Umnova, 1976). But the granules and tubercules are too densely placed on the vesicle of *Eisenackitina dolioliformis*?. The vesicle is next to the present granules/tubercules sometimes not smooth but felt-like. Hence we cannot assign the specimens to typical *Eisenackitina dolioliformis*.
It is tempting to assign the specimens of *Eisenackitina dolioliformis*? and *Eisenackitina* cf. *dolioliformis* as specimens of *Eisenackitina dolioliformis*. Differences on how the ornamentation is placed on the vesicle and the outline of the specimens cause that these specimens cannot be assigned as specimens of *Eisenackitina dolioliformis*.

Eisenackitina cf. *dolioliformis*

Plate II.5.2., specimens 4-8

Material: 1 specimen from JM 08-66 (unit 1), 8 specimens from JM 08-67 (unit 1), 6 specimens from JM 08-69 (unit 1), 1 specimen from JM 08-70 (unit 1), 3 specimens from JM 08-71 (unit 1).

Dimensions: L: 131-165-240 µm (n=11); Dp: 78-98-119 µm (n=14); Dc: 50-55-65 µm (n=3).

Description: we refer for the description to Umnova, 1976 and additional description to Nestor, 1994.

Discussion: The species has the dimensions and general outline of *Eisenackitina dolioliformis*. But the ornamentation is very densely distributed over the vesicle wall and the ornamentation is smaller and finer in comparison with typical *Eisenackitina dolioliformis* (Umnova, 1976). Furthermore *Eisenackitina* cf. *dolioliformis* has a basal edge that is sometimes too sharp although there is a tendency to some rounding. Hence we cannot assign the specimens to typical *Eisenackitina dolioliformis*.

Eisenackitina sp. 1

Plate II.5.5., specimens 11-16; Plate II.5.6., specimens 1-4

Material: 39 specimens from JM 08-83 (unit 1), 1 specimen from JM 08-84 (unit 1).

Dimensions: L: 190-225-300 µm (n=21); Dp: 80-101-122 µm (n=25); Dc: 62-70-80 µm (n=14).

Description: The species has a flat to convex base, sometimes wearing a wide mucron. The mucron can also be indistinct and/or hidden. The basal edge is rounded. The vesicle is subcylindrical, slightly narrowing to the aperture, and flanks that can be slightly convex. A short neck can be present, although in most cases it cannot be or hardly be distinguished. The body is ornamented with granules and tubercules, biggest at the antiapertural pole of the species. The ornamentation decreases in size going to the aperture and is almost absent at the aperture. Concentrical rings can be present on the vesicle below the aperture.

Discussion: Two specimens show an operculum. The other specimens do not show any closing structure. Following the definitions of Paris *et al.*, 1999 this species has been included into the genus of *Eisenackitina*. The species shows resemblance with *Eisenackitina dolioliformis* (Umnova, 1976). But the L/Dp ratio in *Eisenackitina* sp. 1 is higher and the base can be convex. It is distinguished from *Belonechitina aspera* (Nestor, 1980b) by the granules that are a lot thicker and the base can be flat. *Belonechitina postrobusta* (Nestor, 1980b) has spines that are finer. *Belonechitina* sp. 1 has very densely placed, finer spines.

Eisenackitina sp. 2

Plate II.5.7., specimens 13-16; Plate II.5.8., specimens 1, 2

Material: 24 specimens from JM 08-90 (unit 1), 2 specimens from JM 08-99 (unit 2).

Dimensions: L: 169-234-304 µm (n=14); Dp: 80-109-130 µm (n=21); Dc: 50-64-78 µm (n=10).

Description: The species has a flat to slightly convex base and a rounded basal edge. The maximal width is quickly reached starting from the base towards the aperture. After the maximal width has been reached the vesicle narrows straight towards the aperture, but not that much. No neck is visible and the vesicle is sealed by an operculum. It is ornamented with little granules to ridges, often densely placed and the ornamentation often touch each other.

Discussion: The species can be confused with *Belonechitina postrobusta* (Nestor, 1980b). But *Belonechitina postrobusta* has a Dp-value that is lower, it doesn't have an operculum and it is ornamentated with spines with a multipodal base.

Discussion on bio- and chronostratigraphy with chitinozoans

We have subdivided the chitinozoan results by the units where they are present as almost every unit (except unit 1 + unit 2) contain their own assemblage of chitinozoans.

Unit 1 + Unit 2

From the base of the section up to sample JM 08-83 the sediments cannot be correlated with a known chitinozoan biozone as none of the index species is present. Although we have the presence of *Bursachitina conica* and *Eisenackitina causiata*. These chitinozoans have their first appearance in the *Eisenackitina dolioliformis* Biozone (Loydell *et al.*, 2003 & 2010; Nestor, 2010) which occurs in the lower to middle Telychian (Nestor, 2012). But *Eisenackitina dolioliformis* starts higher in sample JM 08-83. In the basal part of the section only specimens of this species in open nomenclature does occur (as *Eisenackitina dolioliformis*? and *Eisenackitina* cf. *dolioliformis*). From sample JM 08-74 to sample JM 08-82 these specimens do not occur anymore. In these samples *Conochitina elongata* does occur. It has his last occurrence at the lower boundary of the *Eisenackitina dolioliformis* Biozone in Baltica (Nestor, 2012). But *Conochitina leviscapulae* does occur in the same sample where *Conochitina elongata* does occur (in sample JM 08-75). This species is known to occur starting in the *Eisenackitina dolioliformis* Biozone (Loydell *et al.*, 2003 & 2010; Mullins & Loydell, 2001; Nestor, 2012). So most probably we can situate the sediments below sample JM 08-83 in the *Eisenackitina dolioliformis* Biozone although *Eisenackitina dolioliformis* is not present. *Cyathochitina kuckersiana* and *Cyathochitina campanulaeformis* have their last appearance in the lower part of the *Eisenackitina dolioliformis* Biozone on eastern Baltica (Nestor, 2012). Although Mullins & Loydell (2001) found in the Banwy River section, Wales *Cyathochitina kuckersiana* until the *lapworthi* graptolite Biozone (upper Telychian). However this species is illustrated by them until the possible *sartorius*-lower *griestoniensis* graptolite Biozone. It can be questioned if the species really occurs until the *lapworthi* graptolite Biozone. *Belonechitina* sp. 2 does occur in three samples (JM 09-116, JM 08-80, JM 08-82) of the lower part of unit 1.

From sample JM 08-83 and further upwards *Eisenackitina dolioliformis* does occur indicating clearly the *Eisenackitina dolioliformis* Biozone. This biozone is present until sample JM 08-99. The presence of *Conochitina emmastensis*, that has his first occurrence in sample JM 08-84, does also confirms this. In Baltica this species starts to occur at almost the same level as *Eisenackitina dolioliformis* (Nestor, 2012). *Bursachitina conica*, *Eisenackitina causiata* and *Conochitina leviscapulae* does also occur; species that occur below sample JM 08-83. *Cyathochitina kuckersiana* has his last occurrence in sample JM 08-87. *Sphaerochitina* sp. 1 occurs in three samples and coincide with the acme of *Ancyrochitina* spp.

As mentioned earlier the preservation of the chitinozoans is less in unit 2 in comparison with unit 1. Hence the ranges of the chitinozoans has to be interpreted more carefully.

Starting from sample JM 08-99 the *Angochitina longicollis* Biozone, from the middle Telychian, does occur. However *Angochitina longicollis* has only been observed from this sample. Many species from the underlying biozone still does occur in this biozone like *Bursachitina conica*, *Eisenackitina causiata*, *Eisenackitina dolioliformis* and *Conochitina emmastensis*. *Conochitina praeproboscifera* starts to occur in the underlying sample JM 08-95. This species already occurs in the underlying *Eisenackitina dolioliformis* Biozone in some cores of Baltica (Loydell *et al.*, 2010; Nestor, 1994 & 2010) and according to Mullins & Loydell (2001) in the Banwy River section, Wales. Nestor (2012) indicates that in some drill cores of East Baltica *Conochitina praeproboscifera* appear at this level. In the Aizpute-41 core (Loydell *et al.*, 2003) and the Ventspils D-3 core (Loydell & Nestor, 2005) it starts to occur in the *Angochitina longicollis* Biozone after the first occurrence of *Angochitina longicollis*. *Conochitina praeproboscifera* is limited in the cores of eastern Baltica to the top of the *Angochitina longicollis* Biozone (middle Telychian; Loydell & Nestor, 2005; Loydell *et al.*, 2003 & 2010; Nestor, 2010). The first occurrence of *Eisenackitina inanulifera* in the top of the *Eisenackitina dolioliformis* Biozone do not contradict with the findings in the

Kolka-54 core (Loydell, 2010). The presence of *Belonechitina cavei*, *Belonechitina meifodensis* and *Calpichitina densa* do not contradict the assignment in the *Angochitina longicollis* biozone (Loydell *et al.*, 2003, 2010; Loydell & Nestor, 2005; Mullins & Loydell, 2001; Nestor, 2010 & 2012). *Belonechitina cavei* occurs until the upper part of the *Angochitina longicollis* Biozone (middle Telychian; Mullins & Loydell, 2001; Nestor, 2012). Hence limiting the upper boundary of this unit to this level. *Lagenochitina* sp. 2 is an easily recognizable species occurring from the top of the *Eisenackitina dolioliformis* Biozone at least into the *Angochitina longicollis* Biozone. Interesting is the presence of *Cyathochitina kuckersiana* and *Cyathochitina* spp. in sample JM 08-107. These specimens are not so nicely preserved and possibly the result of reworking. Further upwards of sample JM 08-107 (samples JM 08-108 and JM 08-109) the chitinozoans are poorly to very poorly preserved and giving not much biostratigraphical information. Hence we prefer to limit the *Angochitina longicollis* Biozone at sample JM 08-107. No information about the age is known from the outcrop where JM 08-108 and JM 08-109 occurs.

Unit 3

Conochitina acuminata and *Conochitina proboscifera* occurs in unit 3. Especially *Conochitina acuminata* is interesting because the time range is shorter (Nestor, 2012) and the time range completely overlaps with *Conochitina proboscifera* that appears earlier and disappears later. *Conochitina acuminata* has a range from the upper Telychian up to the Llandovery-Wenlock boundary (the exact level of this is not known) on eastern Baltica. This is also the range given by the chitinozoans for this unit.

Unit 4

The two samples of unit 4 contain only very poorly to poorly preserved chitinozoans. It is not possibly to assign this unit to a biozone. The presence of one specimen of *Calpichitina* sp. indicate a range of Ordovician to Lower Devonian (Paris *et al.*, 1999) for unit 4.

Unit 5

Two chitinozoan species do occur in unit 5: *Conochitina claviformis* and *Eisenackitina spongiosa*. *Conochitina claviformis* has a long range in eastern Baltica (Nestor, 2012) ranging from the lower Sheinwoodian to the upper Gorstian. *Eisenackitina spongiosa* has a much shorter range and it occurs in the lower Homerian. Hence unit 5 can be placed into the lower Homerian

Unit 6

Sample JM 08-114 contains *Conochitina pachycephala*, *Conochitina* cf. *pachycephala* and *Sphaerochitina lycoperdoides*?. *Conochitina pachycephala* has a range of lower Homerian to upper Gorstian on eastern Baltica (Nestor, 2012). The specimen *Sphaerochitina lycoperdoides*? has been placed in open nomenclature and hence we cannot use it to assign an age to this sample. It occurs in the upper Homerian where it even defines a biozone (globally Verniers *et al.*, 1995; east Baltic Nestor, 2012). Grahn (1996) has found that this species occurs higher up into the lower Gorstian. So if this species really exists in sample JM 08-114

it can placed in the upper Homerian to possibly the lower Gorstian and it belongs to the *Sphaerochitina lycoperdoides* Biozone. But caution is needed because the determination is open nomenclature. One specimen of *Cyathochitina* sp. occurs in this sample. But it is badly preserved and possibly reworked.
Sample JM 08-115 contains *Ancyrochitina* spp. and chitinozoans that cannot be determined to genus level. Hence not so much information about the age can be given for this sample.
In sample JM 08-116 *Angochitina echinata*, *Belonechitina latifrons* and *Conochitina* cf. *fortis* occurs. *Angochitina echinata* occurs from the middle Gorstian to at least the end of the Ludfordian and *Belonechitina latifrons* starts a bit earlier from the middle Gorstian to the lower Ludfordian. These ranges are both from east Baltic drill cores (Nestor, 2009). It means that sample JM 08-116 has a range beginning from the basal occurrence of *Angochitina echinata* in the middle Gorstian up to the last occurrence of *Belonechitina latifrons* in the lower Ludfordian.

5.3.4. Graptolite results

Graptolites occur in multiple levels in unit 1 (20 levels), two levels close to each other in unit 2 and multiple levels in unit 3 (6 levels) and unit 5 (6 levels). The graptolites as described by Vandevelde (1976) and Maes *et al.* (1978) were also reidentified except for levels G1 and G17. The graptolites are studied and identified by Prof. Dr. Petr Storch (Institute of Geology AS CR, Prague, Czech Republic). The results of the identifications and the resulting biozonation is given in table II.5.3.

The graptolite levels from the base of unit 1 (JM 08-22+JM 08-29) up to graptolite level G6 and JM 09-23 belong to the *Spirograptus turriculatus-Streptograptus crispus* Biozones of the lower Telychian. The graptolite levels of G7 up to JM 10-01 + JM 11-16 + JM 11-23 in unit 2 belong to the *Monoclimacis griestoniensis-Monoclimacis crenulata* Biozone of the middle Telychian. The graptolite levels JM 09-17 up to JM 09-37 (with graptolite level G16) belong to the *Cyrtograptus insectus*?-*Cyrtograptus centrifugus* Biozone of the upper Telychian to Llandovery/Wenlock boundary. The graptolite levels from JM 09-21 up to JM 09-38 from unit 5 belong possibly to the *Cyrtograptus murchisoni* Biozone.

Unit	Graptolite level / sample number	*Pristiograptus pristinus*	*Rastrites ex gr. linnaei*	*Monograptus spp.*	*Spirograptus turriculatus*	*Monograptus marri*	*Streptograptus storchi*	*Torquigraptus proteus*	*Monoclimacis spp.*	*Monograptus ex gr. priodon*	*Glyptograptus nebula*	*Torquigraptus spp.*	*Parapetalolithus tenuis*	*Pristiograptus variabilis*	*Streptograptus filiformis*	*Streptograptus exiguus*	*Cochlograptus veles*	*Stimulograptus clintonensis*	*Torquigraptus planus*	*Torquigraptus pseudocommunis*	*Torquigraptus contortus*	*Streptograptus filiformis*	*Monoclimacis griestoniensis*	*Monograptus priodon*	*Torquigraptus australis*	*Pristiograptus ex gr. nudus*	*Torquigraptus tullbergi*	*Monograptus juancarlosi*	*Monoclimacis crenulata*	*Retiolites angustidens*	*Retiolites spp.*	*Monoclimacis woodae*	*Torquigraptus pragensis*	*Pseudoplegmatograptus spp.*	*Retiolites geinitzianus*	*Pristiograptus validus*	*Monoclimacis vomerina*	*Mediograptus kolihai*	*Monoclimacis linnarssoni*	*Pristiograptus spp.*	graptolite indet.	*Apychopsis sp.*	Graptolite biozonation
5	JM 09-38									X																														X			*murchisoni*?
	JM 09-39								X																															X			
	JM 09-19																																								X		
	JM 09-18																		?																								
	JM 09-21																		aff.																								
3	JM 09-37																							X											X		cf.	cf.	X				*insectus*?-*centrifugus*
	JM 09-16								X																																		
	JM 09-36								X															X							X					?							
	JM 09-15																																								X		
	JM 09-17								X																																		
	G16																							X										?	X	cf.	cf.	cf.					
2	JM 10-01 + JM 11-16+23									X														X	?	X																	*griestoniensis-crenulata*
	JM 09-76								X								X						?	X			?		X					X	X								
1	G15																X						?						?													X	
	G14			X					X								X										?						X										
	G13			X													X								X	X					X	cf.										X	
	G12			X													X							X					X	X													
	G11																X						X	X		X	X	aff.	X														
	G10					X											X	X	cf.				X	X																			
	JM 08-25					aff.																																					
	G9									X																																	
	G8							aff.			X			?																													
	G7					X																	aff.	X	X																		
	G6 + JM 09-23	X				X					X						X	X	cf.	X	cf.	aff.																					*turriculatus-crispus*
	JM 09-31	X				X					X		X	X	aff.	X	X	X	cf.																								
	JM 09-26	X									X	X	X																														
	JM 10-30																																								X		
	G5			X																																							
	G4 + JM 09-22					aff.					X	X																															
	G3	X								X																																	
	G2								X																																		
	JM 08-23 + JM 08-28	cf.	X	X	X	cf.	cf.	aff.																																			
	JM 08-22 + JM 08-29	cf.																																									

Table II.5.3. Graptolite results of Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville.

5.3.5. General discussion on graptolite and chitinozoan biostratigraphy and chronostratigraphy

The graptolite identifications and resulting biozonation corroborate the chitinozoan results for unit 1 and unit 2. The two units are deposited continuously in the lower and middle Telychian

The identifications of the graptolites, found in unit 3, refine the results of the chitinozoans. In unit 3 *Conochitina acuminata* occurs, ranging from the *Cyrtograptus lapworthi* Biozone up to the Llandovery/Wenlock boundary in eastern Baltica (Nestor, 2012). Graptolite data suggests the presence of the *Cyrtograptus insectus*? – *Cyrtograptus centrifugus* Biozone excluding the underlying *Cyrtograptus lapworthi* Biozone. Hence unit 3 is placed into the *Cyrtograptus insectus*? – *Cyrtograptus centrifugus* Biozone of the uppermost Telychian to the Llandovery/ Wenlock boundary.

The lithology of unit 4 resembles well these present of unit 2. The outcrops are too poor to make an interpretation possible. A possible repetition of the facies of unit 2 is possible.

The graptolites of unit 5 are possibly correlated with the *Cyrtograptus murchisoni* Biozone. This assignment is unsure and we see that the chitinozoans place unit 5 in the lower Homerian based on the occurrence of *Eisenackitina spongiosa*.

The samples for chitinozoan study of unit 6 are interpreted separately because we do not know the stratigraphic position of these samples and the relationship between each other. The outcrops are too poor to make this possible but they share the same lithology. Sample JM 08-114 belongs possibly to the *Sphaerochitina lycoperdoides* Biozone from the upper Homerian to possibly the lower Gorstian. Sample JM 08-116 indicate the middle Gorstian to lower Ludfordian. It proves for the first time that Ludlow sediments are present in the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville.

Chitinozoan plates

Plate II.5.1. Chitinozoans from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

1. *Bursachitina conica*. L: 163 µm; Dp: 83 µm. JM 08-66. Unit 1.

2. *Bursachitina conica*. L: 191 µm; Dp: 109 µm. JM 09-116. Unit 1.

3. *Bursachitina conica*. L: 160 µm; Dp: 82 µm; Dc: 55 µm. JM 08-83. Unit 1.

4. *Bursachitina conica*. L: 166 µm; Dp: 75 µm; Dc: 50 µm. JM 08-83. Unit 1.

5. *Bursachitina conica*. L: 286 µm; Dp: 148 µm; Dc: 69 µm. JM 08-84. Unit 1.

6. *Bursachitina conica*. L: 180 µm; Dp: 109 µm; Dc: 52 µm. JM 08-84. Unit 1.

7. *Bursachitina conica*. L: 359 µm; Dp: 163 µm; Dc: 95 µm. JM 08-87. Unit 1.

8. *Bursachitina conica*. L: 357 µm; Dp: 207 µm; Dc: <115 µm. JM 08-88. Unit 1.

9. *Bursachitina conica*. L: 310 µm; Dp: 165 µm; Dc: 89 µm. JM 08-90. Unit 1.

10. *Bursachitina conica*. L: 293 µm; Dp: 150 µm; Dc: 83 µm. JM 08-101. Unit 2.

11. *Bursachitina conica*. L: 230 µm; Dp: 179 µm; Dc: 103 µm. JM 08-101. Unit 2.

12. *Bursachitina conica*. L: 250 µm; Dp: 162 µm; Dc: 100 µm. JM 08-101. Unit 2.

13. *Bursachitina conica*. L: 297 µm; Dp: 163 µm; Dc: 101 µm. JM 08-101. Unit 2.

14. *Bursachitina conica*. L: 238 µm; Dp: 150 µm; Dc: 78 µm. JM 08-101. Unit 2.

15. *Bursachitina conica*. L: 314 µm; Dp: 182 µm; Dc: 94 µm. JM 08-101. Unit 2.

16. *Bursachitina conica*. L: 162 µm; Dp: 117 µm; Dc: 63 µm. JM 08-101. Unit 2.

Plate II.5.1.

Plate II.5.2. Chitinozoans from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

1. *Bursachitina conica*. L: 260 µm; Dp: 140 µm; Dc: 70 µm. JM 08-102. Unit 2.

2. *Eisenackitina dolioliformis*?. L: 159 µm; Dp: 95 µm; Dc: 55 µm. JM 08-66. Unit 1.

3. *Eisenackitina dolioliformis*?. L: 215 µm; Dp: 170 µm. JM 08-70. Unit 1.

4. *Eisenackitina* cf. *dolioliformis*. L: 131 µm; Dp: 101 µm; Dc: 50 µm. JM 08-66. Unit 1.

5. *Eisenackitina* cf. *dolioliformis*. L: 190 µm; Dp: 119 µm. JM 08-67. Unit 1.

6. *Eisenackitina* cf. *dolioliformis*. L: 188 µm; Dp: 98 µm; Dc: 55 µm. JM 08-67. Unit 1.

7. *Eisenackitina* cf. *dolioliformis*. L: 140 µm; Dp: 93 µm; Dc: 60 µm. JM 08-69. Unit 1.

8. *Eisenackitina* cf. *dolioliformis*. L: 163 µm; Dp: 83 µm. JM 08-69. Unit 1.

9. *Eisenackitina causiata*. L: 125 µm; Dp: 81 µm; Dc: 57 µm. JM 08-67. Unit 1.

10. *Eisenackitina causiata*. L: 140 µm; Dp: 95 µm. JM 08-67. Unit 1.

11. *Eisenackitina causiata*. L: 88 µm; Dp: 76 µm; Dc: 47 µm. JM 08-69. Unit 1.

12. *Eisenackitina causiata*. L: 110 µm; Dp: 86 µm; Dc: 43 µm. JM 08-70. Unit 1.

13. *Eisenackitina causiata*. L: 159 µm; Dp: 102 µm; Dc: 60 µm. JM 08-84. Unit 1.

14. *Eisenackitina causiata*. L: 141 µm; Dp: 121 µm; Dc: 70 µm. JM 08-84. Unit 1.

15. *Eisenackitina causiata*. L: 63 µm; Dp: 71 µm. JM 08-91. Unit 2.

16. *Eisenackitina causiata*. L: 108 µm; Dp: 77 µm. JM 08-95. Unit 2.

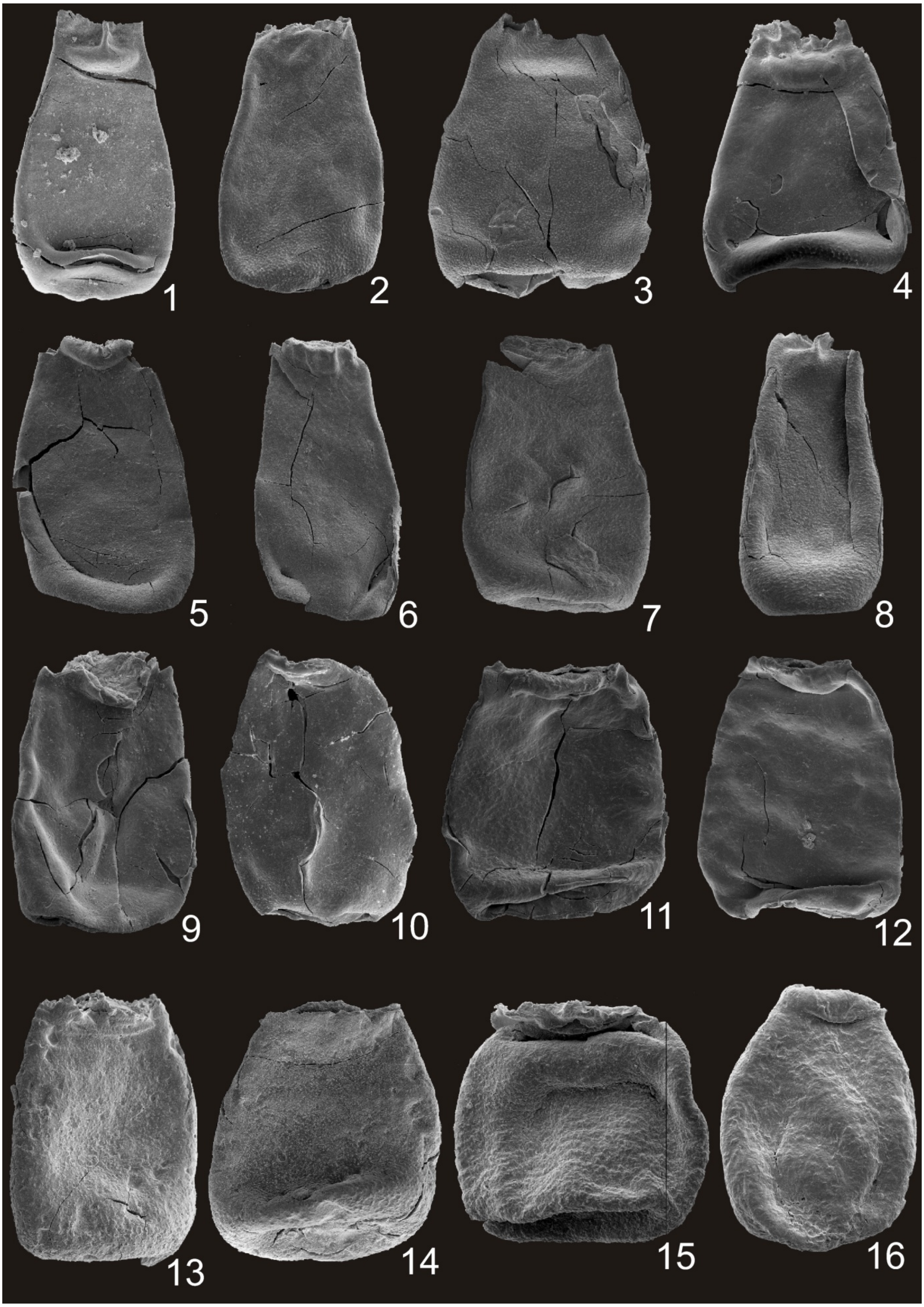


Plate II.5.2.

Plate II.5.3. Chitinozoans from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

1. *Eisenackitina causiata*. L: 131 µm; Dp: 92 µm; Dc: 57 µm. JM 08-101. Unit 2.

2. *Eisenackitina causiata*. L: 127 µm; Dp: 90 µm; Dc: 63 µm. JM 08-101. Unit 2.

3. *Belonechitina* sp. 1. L: 210 µm; Dp: 89 µm; Dc: 59 µm. JM 08-71. Unit 1.

4. *Belonechitina* sp. 1. L: 300 µm; Dp: 90 µm; Dc: 59 µm. JM 08-71. Unit 1.

5. *Conochitina leviscapulae*. L: 108 µm; Dp: 67 µm; Dc: 40 µm. JM 08-75. Unit 1.

6. *Conochitina leviscapulae*. L: 161 µm; Dp: 109 µm; Dc: 70 µm. JM 08-83. Unit 1.

7. *Conochitina leviscapulae*. L: 187µm; Dp: 120 µm; Dc: 70 µm. JM 08-84. Unit 1.

8. *Conochitina leviscapulae*. L: 230 µm; Dp: 130 µm; Dc: 70 µm. JM 08-84. Unit 1.

9. *Conochitina elongata*. L: ≥190 µm; Dp: 57 µm; Dc: ≤39 µm. JM 08-75. Unit 1.

10. *Conochitina elongata*. L: ≥209 µm; Dp: 79 µm; Dc: 37 µm. JM 08-82. Unit 1.

11. *Ancyrochitina* sp. L: 117 µm; Dp: 77 µm; Dc: 31 µm. JM 08-75. Unit 1.

12. Chain of 2 specimens of *Calpichitina* sp. L_{total}: 116 µm. JM 08-76. Unit 1.

13. Chain of 3 specimens of *Desmochitina* sp. L_{total}: 235 µm. JM 09-116. Unit 1.

14. *Belonechitina* sp. 2. L: >139 µm; Dp: 61 µm; Dc: ≤41 µm. JM 09-116. Unit 1.

15. *Belonechitina* sp. 2. L: 230 µm; Dp: 75 µm; Dc: 50 µm. JM 08-80. Unit 1.

16. *Belonechitina* sp. 2. L: >148 µm; Dp: 66 µm; Dc: ≤49 µm. JM 08-82. Unit 1.

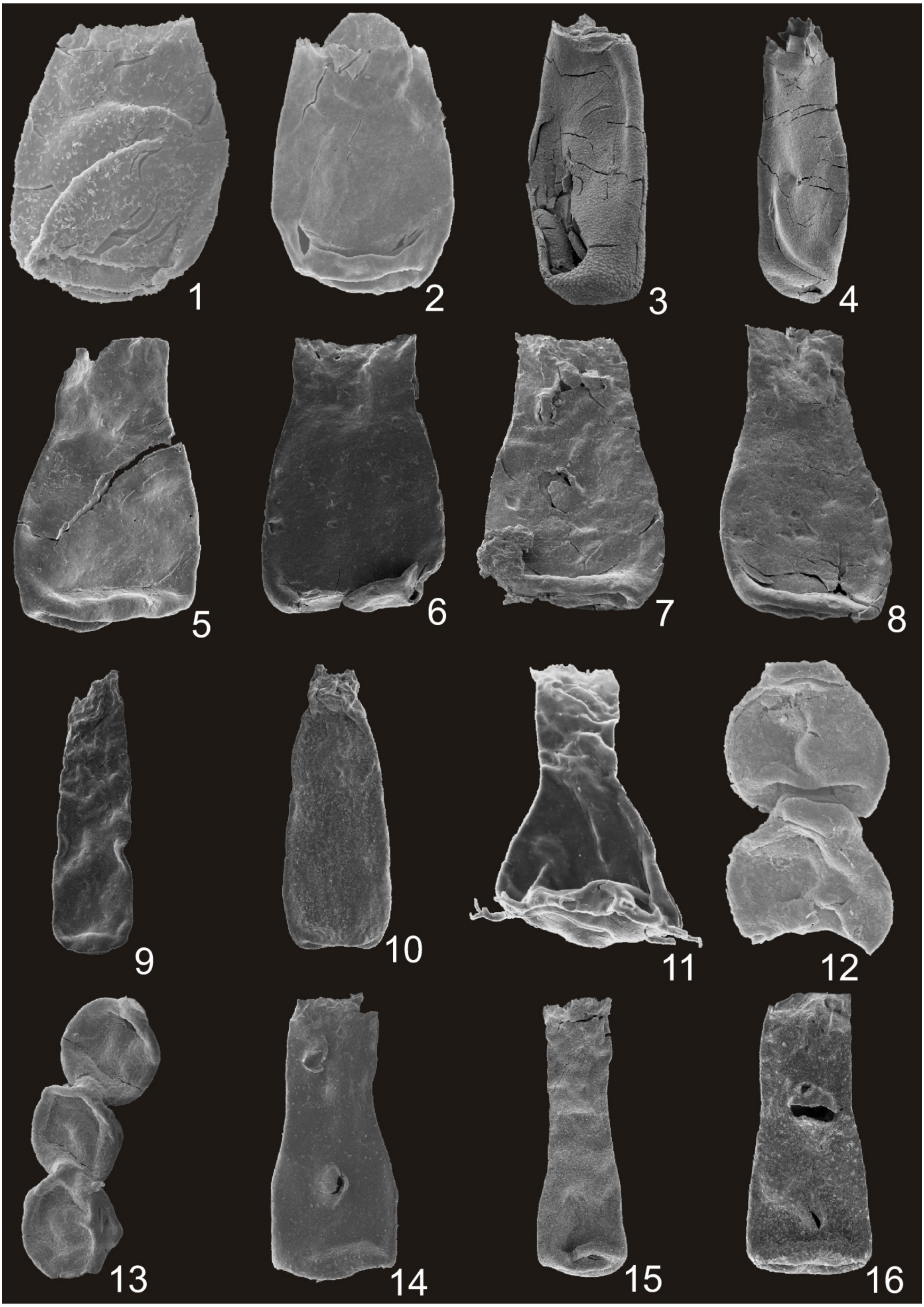


Plate II.5.3.

Plate II.5.4. Chitinozoans from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

1. *Cyathochitina kuckersiana*. L: 141 µm; Dp: 80 µm; Dc: 46 µm. JM 08-82. Unit 1.

2. *Cyathochitina kuckersiana*. L: 231 µm; Dp: 145 µm; Dc: 40 µm. JM 08-84. Unit 1.

3. *Cyathochitina kuckersiana*. L: 255 µm; Dp: 137 µm; Dc: 51 µm. JM 08-87. Unit 1.

4. *Cyathochitina kuckersiana*. L: >147 µm; Dp: 118 µm; Dc: 49 µm. JM 08-87. Unit 1.

5. *Cyathochitina kuckersiana*. L: 239 µm; Dp: 151 µm; Dc: 60 µm. JM 08-87. Unit 1.

6. *Cyathochitina kuckersiana*. L: 228 µm; Dp: 165 µm; Dc: 58 µm. JM 08-87. Unit 1.

7. *Cyathochitina kuckersiana*. L: 243 µm; Dp: 150 µm; Dc: 52 µm. JM 08-87. Unit 1.

8. *Cyathochitina kuckersiana*. L: >180 µm; Dp: 137 µm; Dc: ≤45 µm. JM 08-107. Unit 1.

9. *Cyathochitina campanulaeformis*. L: >208 µm; Dp: 134 µm; Dc: 70 µm. JM 08-80. Unit 1.

10. *Eisenackitina dolioliformis*. L: 199 µm; Dp: 129 µm; Dc: 71 µm. JM 08-83. Unit 1.

11. *Eisenackitina dolioliformis*. L: 195 µm; Dp: 112 µm; Dc: 70 µm. JM 08-83. Unit 1.

12. *Eisenackitina dolioliformis*. L: 200 µm; Dp: 125 µm; Dc: 86 µm. JM 08-83. Unit 1.

13. *Eisenackitina dolioliformis*. L: 200 µm; Dp: 107 µm; Dc: 67 µm. JM 08-83. Unit 1.

14. *Eisenackitina dolioliformis*. L: 201 µm; Dp: 130 µm; Dc: 80 µm. JM 08-83. Unit 1.

15. *Eisenackitina dolioliformis*. L: 155 µm; Dp: 108 µm; Dc: 60 µm. JM 08-83. Unit 1.

16. *Eisenackitina dolioliformis*. L: 216 µm; Dp: 120 µm; Dc: 78 µm. JM 08-83. Unit 1.

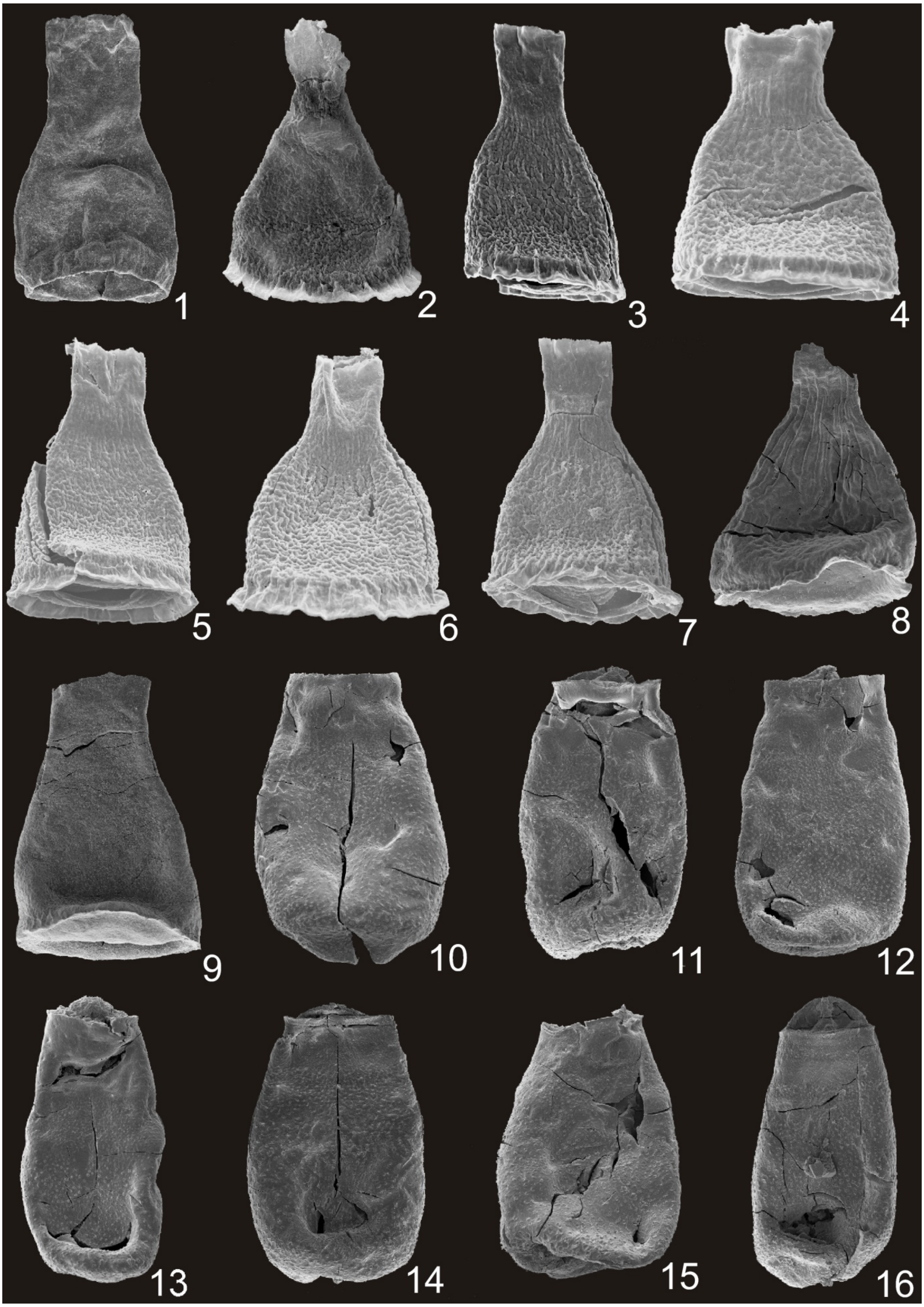


Plate II.5.4.

Plate II.5.5. Chitinozoans from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

1. *Eisenackitina dolioliformis*. L: 202 µm; Dp: 112 µm; Dc: 70 µm. JM 08-84. Unit 1.

2. *Eisenackitina dolioliformis*. L: 200 µm; Dp: 116 µm; Dc: 70 µm. JM 08-84. Unit 1.

3. *Eisenackitina dolioliformis*. L: 175 µm; Dp: 125 µm; Dc: 75 µm. JM 08-84. Unit 1.

4. *Eisenackitina dolioliformis*. L: 170 µm; Dp: 117 µm; Dc: 63 µm. JM 08-84. Unit 1.

5. *Eisenackitina dolioliformis*. L: 190 µm; Dp: 103 µm; Dc: 66 µm. JM 08-84. Unit 1.

6. *Eisenackitina dolioliformis*. L: 179 µm; Dp: 100 µm; Dc: 63 µm. JM 08-84. Unit 1.

7. *Eisenackitina dolioliformis*. L: 150 µm; Dp: 107 µm; Dc: 67 µm. JM 08-84. Unit 1.

8. *Eisenackitina dolioliformis*. L: 182 µm; Dp: 95 µm; Dc: 55 µm. JM 08-90. Unit 1.

9. *Eisenackitina dolioliformis*. L: 161 µm; Dp: 94 µm. JM 08-103. Unit 2.

10. *Eisenackitina dolioliformis*. L: 184 µm; Dp: 123 µm; Dc: 75 µm. JM 08-107. Unit 2.

11. *Eisenackitina* sp. 1. L: 230 µm; Dp: 100 µm; Dc: 70 µm. JM 08-83. Unit 1.

12. *Eisenackitina* sp. 1. L: 221 µm; Dp: 100 µm; Dc: 72 µm. JM 08-83. Unit 1.

13. *Eisenackitina* sp. 1. L: 220 µm; Dp: 110 µm; Dc: 75 µm. JM 08-83. Unit 1.

14. *Eisenackitina* sp. 1. L: 300 µm; Dp: 112 µm; Dc: 70 µm. JM 08-83. Unit 1.

15. *Eisenackitina* sp. 1. L: 236 µm; Dp: 99 µm; Dc: 75 µm. JM 08-83. Unit 1.

16. *Eisenackitina* sp. 1. L: 200 µm; Dp: 85 µm; Dc: 64 µm. JM 08-83. Unit 1.

Plate II.5.5.

Plate II.5.6. Chitinozoans from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

1. *Eisenackitina* sp. 1. L: 238 µm; Dp: 102 µm; Dc: 70 µm. JM 08-83. Unit 1.

2. *Eisenackitina* sp. 1. L: 270 µm; Dp: 107 µm; Dc: 80 µm. JM 08-83. Unit 1.

3. *Eisenackitina* sp. 1. L: 278 µm; Dp: 108 µm; Dc: 70 µm. JM 08-83. Unit 1.

4. *Eisenackitina* sp. 1. L: 250 µm; Dp: 110 µm; Dc: 75 µm. JM 08-84. Unit 1.

5. *Bursachitina* sp. 1. L: 206 µm; Dp: 110 µm; Dc: 67 µm. JM 08-84. Unit 1.

6. *Bursachitina* sp. 1. L: 170 µm; Dp: 90 µm; Dc: 53 µm. JM 08-84. Unit 1.

7. *Bursachitina* sp. 1. L: 180 µm; Dp: 100 µm; Dc: 65 µm. JM 08-84. Unit 1.

8. *Bursachitina* sp. 1. L: 179 µm; Dp: 82 µm; Dc: 48 µm. JM 08-84. Unit 1.

9. *Bursachitina* sp. 1. L: 190 µm; Dp: 102 µm; Dc: 60 µm. JM 08-84. Unit 1.

10. *Bursachitina* sp. 1. L: 154 µm; Dp: 86 µm; Dc: 55 µm. JM 08-84. Unit 1.

11. *Bursachitina* sp. 1. L: 180 µm; Dp: 98 µm; Dc: 60 µm. JM 08-84. Unit 1.

12. *Bursachitina* sp. 1. L: 167 µm; Dp: 87 µm; Dc: 59 µm. JM 08-84. Unit 1.

13. *Conochitina*? *leviscapulae*?. L: 193 µm; Dp: 115 µm; Dc: 61 µm. JM 08-84. Unit 1.

14. *Conochitina*? *leviscapulae*?. L: 189 µm; Dp: 121 µm; Dc: 67 µm. JM 08-84. Unit 1.

15. *Conochitina*? *leviscapulae*?. L: 220 µm; Dp: 130 µm; Dc: 70 µm. JM 08-84. Unit 1.

16. *Eisenackitina* sp. L: 197 µm; Dp: 107 µm; Dc: 60 µm. JM 08-84. Unit 1.

Plate II.5.6.

Plate II.5.7. Chitinozoans from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

1. *Conochitina emmastensis*. L: 225 µm; Dp: 95 µm; Dc: 52 µm. JM 08-84. Unit 1.

2. *Conochitina emmastensis*. L: 260 µm; Dp: 120 µm; Dc: 72 µm. JM 08-87. Unit 1.

3. *Conochitina emmastensis*. L: 238 µm; Dp: 102 µm; Dc: 69 µm. JM 09-33. Unit 2.

4. *Conochitina emmastensis*. L: ≥265 µm; Dp: 95 µm; Dc: ≤45 µm. JM 08-103. Unit 2.

5. *Sphaerochitina* sp. 1. L: 180 µm; Dp: 70 µm; Dc: 30 µm. JM 08-85. Unit 1.

6. *Sphaerochitina* sp. 1. L: 195 µm; Dp: 73 µm; Dc: 30 µm. JM 08-85. Unit 1.

7. *Sphaerochitina* sp. 1. L: >145 µm; Dp: 70 µm; Dc: 30 µm. JM 08-86. Unit 1.

8. *Ancyrochitina* sp. L: 123 µm; Dp: 76 µm; Dc: 25 µm. JM 08-87. Unit 1.

9. *Ramochitina* sp. L: 210 µm; Dp: 62 µm; Dc: 22 µm. JM 08-87. Unit 1.

10. *Bursachitina* aff. *conica*. L: ≥278 µm; Dp: 150 µm; Dc: ≤93 µm. JM 08-88. Unit 1.

11. *Bursachitina* aff. *conica*. L: 328 µm; Dp: 178 µm; Dc: 112 µm. JM 08-90. Unit 1.

12. *Bursachitina* aff. *conica*. L: 315 µm; Dp: 148 µm; Dc: 85 µm. JM 08-90. Unit 1.

13. *Eisenackitina* sp. 2. L: 285 µm; Dp: 130 µm; Dc: 78 µm. JM 08-90. Unit 1.

14. *Eisenackitina* sp. 2. L: 169 µm; Dp: 86 µm; Dc: 50 µm. JM 08-90. Unit 1.

15. *Eisenackitina* sp. 2. L: 230 µm; Dp: 99 µm; Dc: 60 µm. JM 08-90. Unit 1.

16. *Eisenackitina* sp. 2. L: 230 µm; Dp: 119 µm; Dc: 69 µm. JM 08-90. Unit 1.

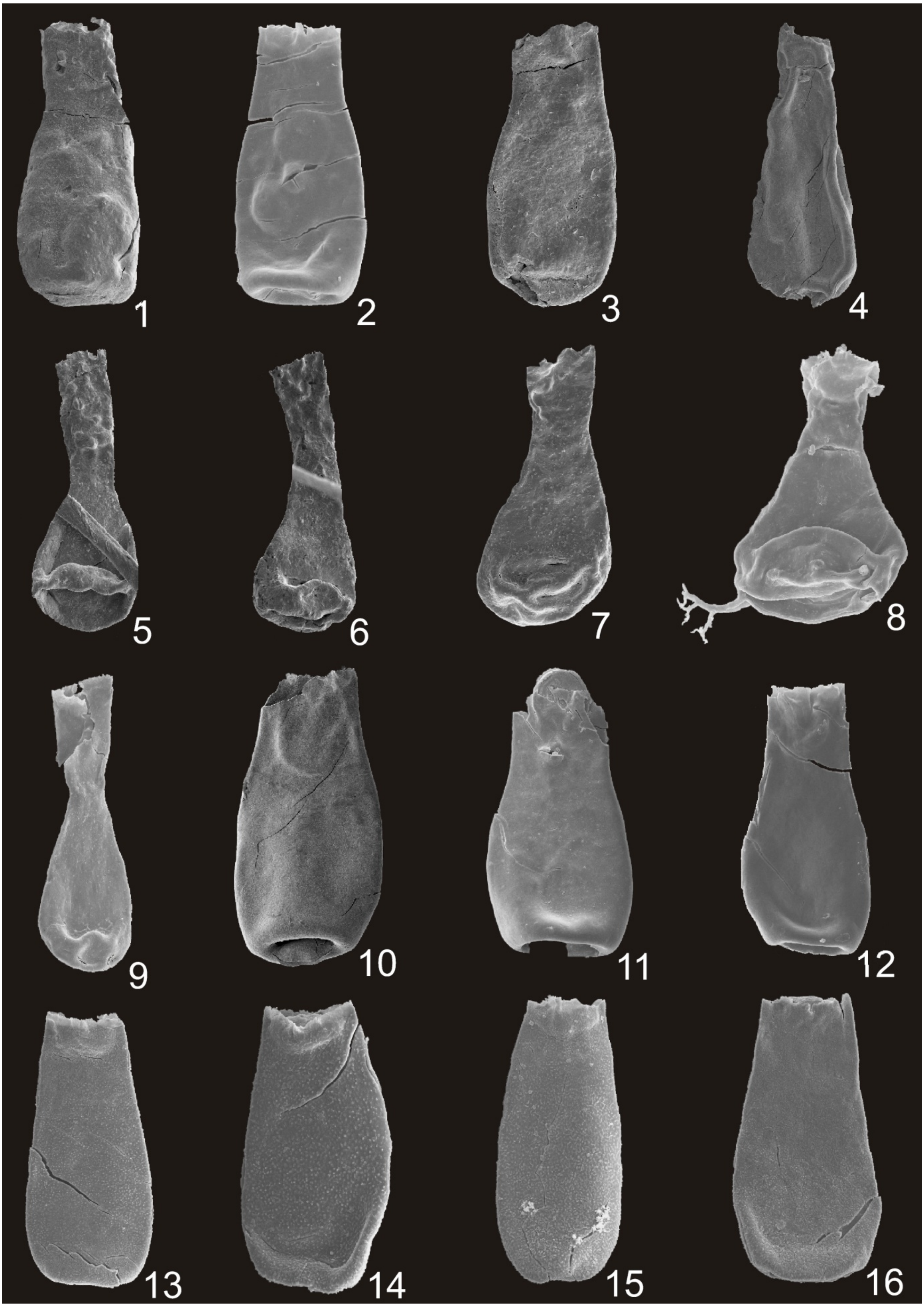


Plate II.5.7.

Plate II.5.8. Chitinozoans from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

1. *Eisenackitina* sp. 2. L: 304 µm; Dp: 126 µm; Dc: 67 µm. JM 08-90. Unit 1.

2. *Eisenackitina* sp. 2. L: 204 µm; Dp: 93 µm; Dc: 56 µm. JM 08-99. Unit 2.

3. *Rhabdochitina* sp. L: >280 µm; Dp: 50 µm; Dc: ≤41 µm. JM 08-91. Unit 2.

4. *Ramochitina* sp. L: ≥160 µm; Dp: 83 µm; Dc: 38 µm. JM 08-96. Unit 2.

5. *Lagenochitina* sp. 1. L: 221 µm; Dp: 110 µm; Dc: 50 µm. JM 08-96. Unit 2.

6. *Lagenochitina* sp. 1. L: 228 µm; Dp: 110 µm; Dc: 40 µm. JM 08-103. Unit 2.

7. Detail of plate 8, picture 6 showing the ornamentation of *Lagenochitina* sp. 1. JM 08-103. Unit 2.

8. *Lagenochitina* sp. 1. L: >163 µm; Dp: 94 µm; Dc: ≤40 µm. JM 08-107. Unit 2.

9. *Lagenochitina* sp. 1. L: 183 µm; Dp: 94 µm; Dc: 34 µm. JM 08-107. Unit 2.

10. *Belonechitina* sp. L: 200 µm; Dp: 80 µm; Dc: 40 µm. JM 08-96. Unit 2.

11. *Conochitina mathrafalensis*?. L: 220 µm; Dp: 90 µm; Dc: 50 µm. JM 08-93. Unit 2.

12. *Conochitina praeproboscifera*. L: >220 µm; Dp: 70 µm. JM 08-95. Unit 2.

13. *Conochitina praeproboscifera*. L: >230 µm; Dp: 80 µm. JM 08-95. Unit 2.

14. *Conochitina praeproboscifera*. L: >260 µm; Dp: 85 µm. JM 08-103. Unit 2.

15. *Angochitina longicollis*. L: 177 µm; Dp: 82 µm; Dc: 31 µm. JM 08-99. Unit 2.

16. *Ramochitina* sp. L: 128 µm; Dp: 97 µm; Dc: 32 µm. JM 08-99. Unit 2.

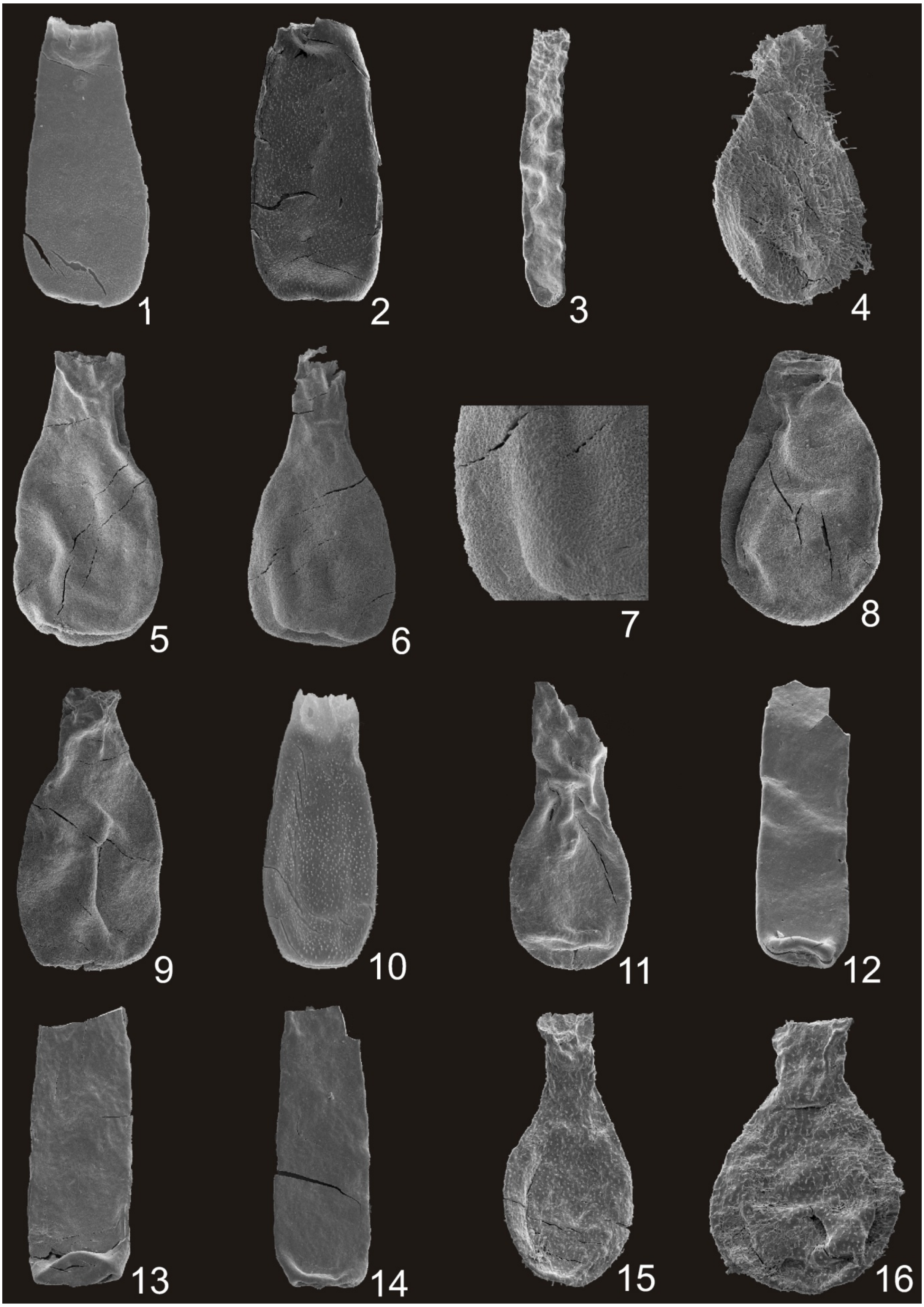


Plate II.5.8.

Plate II.5.9. Chitinozoans from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

1. *Bursachitina* sp. L: 254 µm; Dp: 154 µm; Dc: 92 µm. JM 08-101. Unit 2.

2. *Eisenackitina inanulifera*. L: 111 µm; Dp: 71 µm; Dc: 43 µm. JM 08-105. Unit 2.

3. Chain of 3 specimens of *Calpichitina* sp. L_{total}: 223 µm. JM 08-106. Unit 2.

4. *Eisenackitina* aff. *anulifera*. L: 111 µm; Dp: 69 µm; Dc: ≤37 µm. JM 08-107. Unit 2.

5. *Spinachitina* sp. L: 265 µm; Dp: 95 µm; Dc: 60 µm. JM 08-107. Unit 2.

6. *Cyathochitina* sp. L: ≥260 µm; Dp: 124 µm; Dc: 60 µm. JM 08-107. Unit 2.

7. *Cyathochitina* sp. L: 170 µm; Dp: 89 µm; Dc: 37 µm. JM 08-107. Unit 2.

8. *Belonechitina* sp. L: 291 µm; Dp: 90 µm; Dc: 55 µm. JM 08-107. Unit 2.

9. *Spinachitina* sp. L: 190 µm; Dp: 78 µm; Dc: 45 µm. JM 08-107. Unit 2.

10. *Spinachitina* sp. L: 185 µm; Dp: 68 µm; Dc: 46 µm. JM 08-107. Unit 2.

11. *Belonechitina* sp. L: 177 µm; Dp: 59 µm; Dc: 42 µm. JM 08-107. Unit 2.

12. *Conochitina acuminata*. L: >139 µm; Dp: 67 µm; Dc: ≤50 µm. JM 08-110. Unit 3.

13. *Conochitina* cf. *proboscifera*. L: >170 µm; Dp: 70 µm. JM 09-117. Unit 3.

14. *Calpichitina* sp. L: 108 µm; Dp: 99 µm. JM 10-51. Unit 4.

15. *Conochitina claviformis*. L: >325 µm; Dp: 65 µm; Dc: ≤50 µm. JM 08-113. Unit 5.

16. *Sphaerochitina* sp. L: 118 µm; Dp: 59 µm; Dc: 20 µm. JM 09-27. Unit 5.

Plate II.5.9.

Plate II.5.10. Chitinozoans from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

1. *Eisenackitina spongiosa*. L: 122 µm; Dp: 79 µm; Dc: 51 µm. JM 09-27. Unit 5.

2. *Eisenackitina spongiosa*. L: 130 µm; Dp: 77 µm; Dc: 57 µm. JM 09-27. Unit 5.

3. *Eisenackitina spongiosa*. L: 137 µm; Dp: 78 µm; Dc: 60 µm. JM 09-27. Unit 5.

4. *Eisenackitina spongiosa*. L: 150 µm; Dp: 73 µm; Dc: 50 µm. JM 09-27. Unit 5.

5. *Eisenackitina spongiosa*. L: 120 µm; Dp: 65 µm; Dc: 43 µm. JM 09-27. Unit 5.

6. *Conochitina* cf. *pachycephala*. L: >320 µm; Dp: 94 µm; Dc: 55 µm. JM 08-114. Unit 6.

7. *Conochitina pachycephala*. L: >265 µm; Dp: 95 µm; Dc: <65 µm. JM 08-114. Unit 6.

8. *Sphaerochitina lycoperdoides*?. L: 145 µm; Dp: 78 µm; Dc: 26 µm. JM 08-114. Unit 6.

9. *Ancyrochitina* sp. L: 156 µm; Dp: 82 µm; Dc: 35 µm. JM 08-115. Unit 6.

10. *Angochitina echinata*. L: 159 µm; Dp: 72 µm; Dc: 34 µm. JM 08-116. Unit 6.

11. *Belonechitina latifrons*. L: >190 µm; Dp: 88 µm; Dc: <55 µm. JM 08-116. Unit 6.

12. *Conochitina* cf. *fortis*. L: 250 µm; Dp: 112 µm; Dc: 59 µm. JM 08-116. Unit 6.

Plate II.5.10.

Graptolite plate

Plate II.5.11. Graptolites from Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville.

A, L – *Monograptus priodon* (Bronn), limonitized specimens preserved in relief: A – (Sample F, No. P1903-F27), L – (Sample JM11-01). B, I – *Monoclimacis vomerina* (Nicholson), limonitized specimens preserved in relief: B – (Sample F, P1903-F8), I – (Sample F, No. 1903-F2). C1-C3, D, O, P1-P2 – *Mediograptus morleyae* Loydell & Cave, limonitized specimens in relief with partly preserved periderm, partly flaked off: C1-C3, group of three rhabdosomes and P1-P2, group of two rhabdosomes – (Sample F, No. P1903-F2); D – (Sample F, P1903-F31), O – (Sample JM11-02). E – *Monograptus pseudocultellus* Bouček , limonitized specimen in relief, partly flaked off, (Sample F, No. P1903-F34). F – *Monoclimacis kettneri* (Bouček), external mould of limonitized specimen preserved in relief, (Sample L, No. P1903-L2). G – *Cyrtograptus* sp., cf. *insectus* Bouček, proximal fragment of flattened specimen, (Sample F, No. 1902-F5). H – *Mediograptus kodymi* (Bouček), external mould of limonitized specimen preserved in low relief, (Sample J, No. 1904-J4). J, K – *Streptograptus exiguus* (Lapworth), flattened specimens: J – (Sample B, No. P1903-B16), K – (Sample B, No. P1903-B15), M – *Barrandeograptus pulchellus* (Tullberg), external mould with remains of periderm preserved in relief, (Sample F, No. P1903-F2). N – *Monoclimacis* sp., cf. *geinitzi* (Bouček), flattened, partly pyritized rhabdosome, (Sample D, No. P1903-D11). Q – *Torquigraptus australis* Štorch , incomplete flattened rhabdosome, (Sample E, No. P1903-E2). R – *Retiolites angustidens* Elles & Wood, partly limonitized rhabdosome, (Sample C, No. P1903-C7). All specimens x 6.

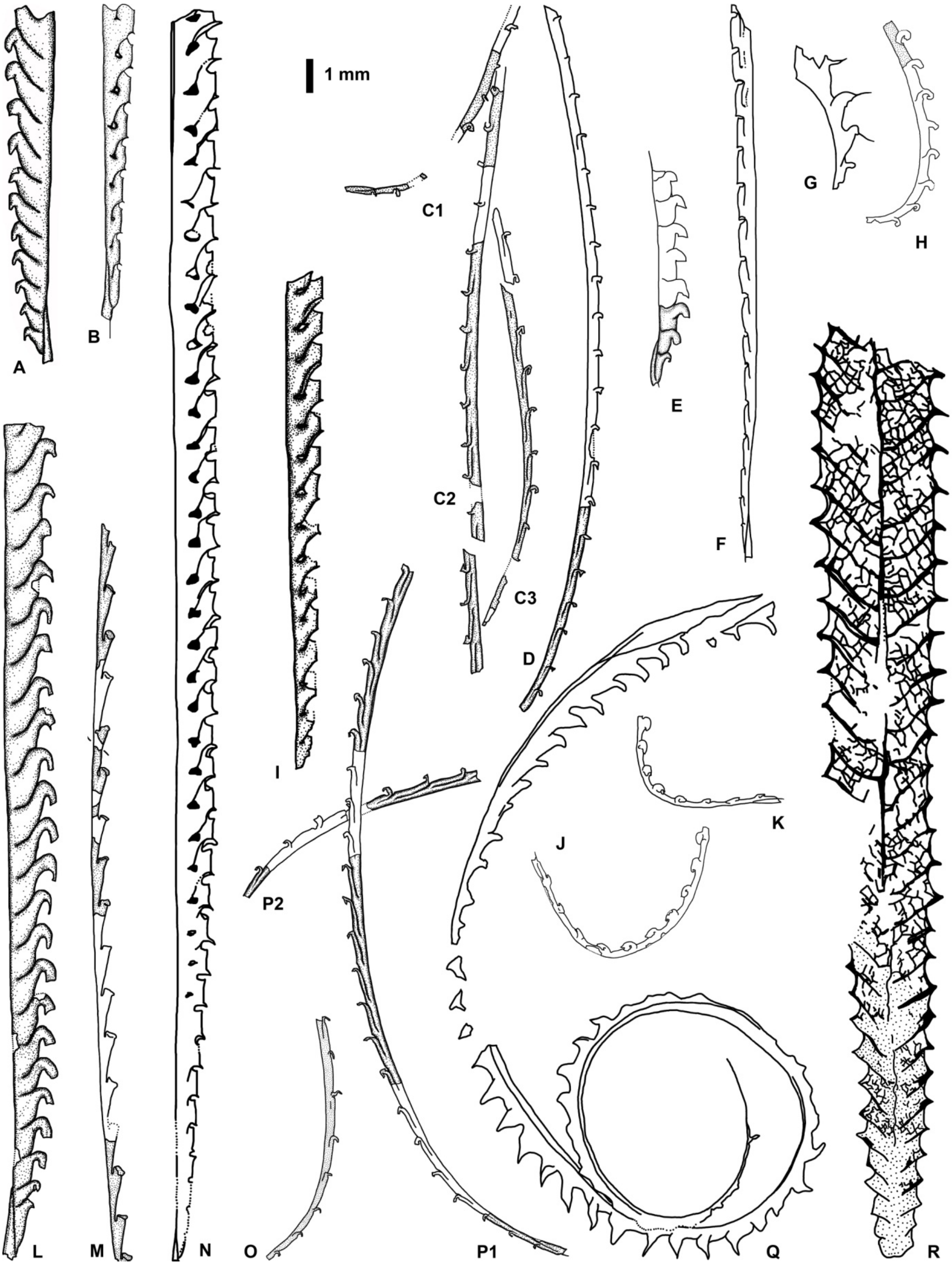


Plate II.5.11.

6. Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville

6.1. Location

The section is situated in a north-south orientated ravine in the flanks of the Meuse valley about 1200 m east of Parc de la Neuville. Outcrops occur discontinuously along both sides of the flancs of the brooklet. Outcrops are more continuous along a pathway west of the brooklet occurring in the western flank.

6.2. Earlier studies

The volcaniclastic layers present in the section are mainly described in chapter II.7.

Malaise & Lespineux (1904) described for the first time in this locality with graptolites. They observe quartzitic, ferruginous shale that are greenish becoming brownish by weathering dipping to the south occurring on the left bank of the brooklet along the road 60 meters to south of the Grand'Route. The following graptolites have been found: *Monoclimacis* (*Monograptus*) *vomerina* which dominates, *Monograptus bohemicus*, *M. nilssoni* and *M. priodon*. They occur in the graptolitic facies of the Naninne Formation according to these authors. Eighty meters further to the south they find a porphyroid identical to these of Parc de la Neuville.

Michot (1932a) described the section going from north to south as follows:

a. Green shale and sandy shale with a dip of 50° to the south. These are identical as in the ravine 700 m east of Parc de la Neuville.

b. Red shale containing locally small intercalations of green shale, with a thickness of 13 meters.

c. Green shale with a thickness of 5 meters.

d. "Arkose" with a chloritic cement, with a thickness of 1.5 meters.

e. Finely laminated, green or bluish green shale identical to these outcropping along the southern pond of Parc de la Neuville. Directly southwards of the bridge over the brooklet the following graptolites have been found in these shales: *Retiolites geinitzianus*, *Monograptus vomerinus* and *M. capillaceus*. This association characterizes according to him the *Cyrtograptus murchisoni* Biozone

f. Further southwards along the road bluish shale occurs from the Ordovician.

The same author, two years later, in 1934 gives a more detailed description of the section, especially from unit a which he divided into three more units. He divided the section in the following units (the same numbering has been used as Michot, 1934) going southwards (see also fig. II.3.3):

a. Green and blue shale outcropping over the western flank over a length of 40 meters. They have an average dip of 50° to the south and a thickness of 30 meters.

b. Interstratified in these shales a blue, greenish quartzitic keratophyre level occurs with a thickness of 0.5 meter.

c. Green shale outcropping over a length of 20 meters, with a thickness of 15 meters. In these shales Malaise & Lespineux (1904) has found the following graptolites: *Monograptus vomerinus*, *M. priodon*, *M. nilssoni* and *M. bohemicus*. Michot (1934) could not find this graptolite level. But he is quite sure that the identifications were probably wrong. The two first graptolites occur in the basal part of the Wenlock whereas the two last graptolites occur in the lower Ludlow.

d. Red shale with locally intercalations of green shale. They dip 60° to 70° to the south and have a thickness of 13 meters.

e. Green shale with a thickness of 5 meters.

f. “Arkose” with a coarse grain size and a chloritic cement. It has a thickness of 1.5 meters.

g. Blue or blue greenish, laminated, slightly sandy shale. The shales are identical to these outcropping along the southern pond in Parc de la Neuville, directly north of the locality with *Cyrtograptus murchisoni*. Directly southwards of the bridge over the brooklet the following graptolites have been found: *Retiolites geinitzianus*, *Monograptus vomerinus* and *Monograptus capillaceus*. This association characterizes according to him the *Cyrtograptus murchisoni* Biozone.

Van Doorne (1975) described the section from north to south starting from the southern edge of the bridge of the Grand’Route over the brooklet, taking this zero datum point:

0-10 m: No outcrops are present.

15.3 m: Green brown shale with a thickness of 1.13 meters.

27.7 m: Greyish shale with a thickness of 3.75 meters.

Stratigraphically 0.8 meters higher grey-blue shale occur. The shale resembles, according to him, to the northernmost occurring shale of the ravine 700 m east of Parc de la Neuville. The shale reaches a thickness of 1.15 meters and correspond to unit a of Michot (1934). The outcrop extends until 35.3 meters.

Over a distance of 7 meters pieces of a tuff occur scattered over the flanks of the ravine. According to Van Doorne (1975) it corresponds to unit b of Michot (1934).

Pale brown to grey shales is succeeded with a thickness of 1.2 meters. The shales are followed by pieces of a tuff scattered over the surface over a distance of 10 meters.

Further southwards, at 60 meters from the datum point, an outcrop occurs of 0.40 m blue-green, glassy shale occur. Supposedly it is here that graptolites have been found by Malaise & Lespineux (1904). The shale is succeeded by shale, sometimes sandy, showing a centimetric to decimetric alternation of colours: blue-green, olive green, green-grey, blue-grey, brown-grey, pale grey, dark green, greenish, black-grey, purple-red. A 0.80 m thick keratophyre level does occur. He interprets this as the levels of unit d and e of Michot (1934).

After an observational gap over 2.1 meters length grey-green shale occur with locally centimetric medium-grained quartzitic nodules. The shale occurs over a distance of 6.6 meters with a thickness of 4.95 meters.

After an observational gap over 3.9 meters length 60 cm of the same shale as above occurs. They are however more finely laminated and paler. The same shale occurs over 1.9 meter after an observational gap of 0.8 meters.

After an observational gap of 1.1 meter dark green, compact shale occurs with a thickness of 0.78 m. Above these shale 8 cm olive green shale occurs succeeded by 7 cm brown-green shale.

Above the latter 12 cm of coarse-grained, strongly weathered tuff occur. Further southwards the tuff becomes more compact. It has a thickness of 2.6 meters and it corresponds to unit f of Michot (1934).

After an observational gap with a supposed thickness of 1.2 meters strata very fine green to olive green shale occurs with a thickness of 3.23 meters. He interprets that this shale corresponds to unit g of Michot (1932a & 1934).

Maes (1976), in his Master thesis, and the resulting publication of Maes *et al.* (1978), has used a different numbering than these of Michot (1934). The section along the brooklet and along the path is given in fig. II.6.1. The litho-, bio- and chronostratigraphy is given in fig. II.6.2. He describes the section as follows (from north to south):

Unit 1: Coarse, brown-grey, slightly quartzitic shale with sporadically a weak lamination. Higher up the shale become less coarse. The minimal thickness is 40 meters.

Unit 2: Dark green shale paler towards the top. They are still rather coarse with a thickness of 8.6 meters.

Unit 3: Alternation of green and red shale. They are fine-grained and brittle, crumbling in small and thin plates. The unit has a minimal thickness of 2.85 meters.

Unit 4: Green and olive green shale with intercalations of fine grey, laminated shale. The unit has a minimal thickness of 5.2 meters.

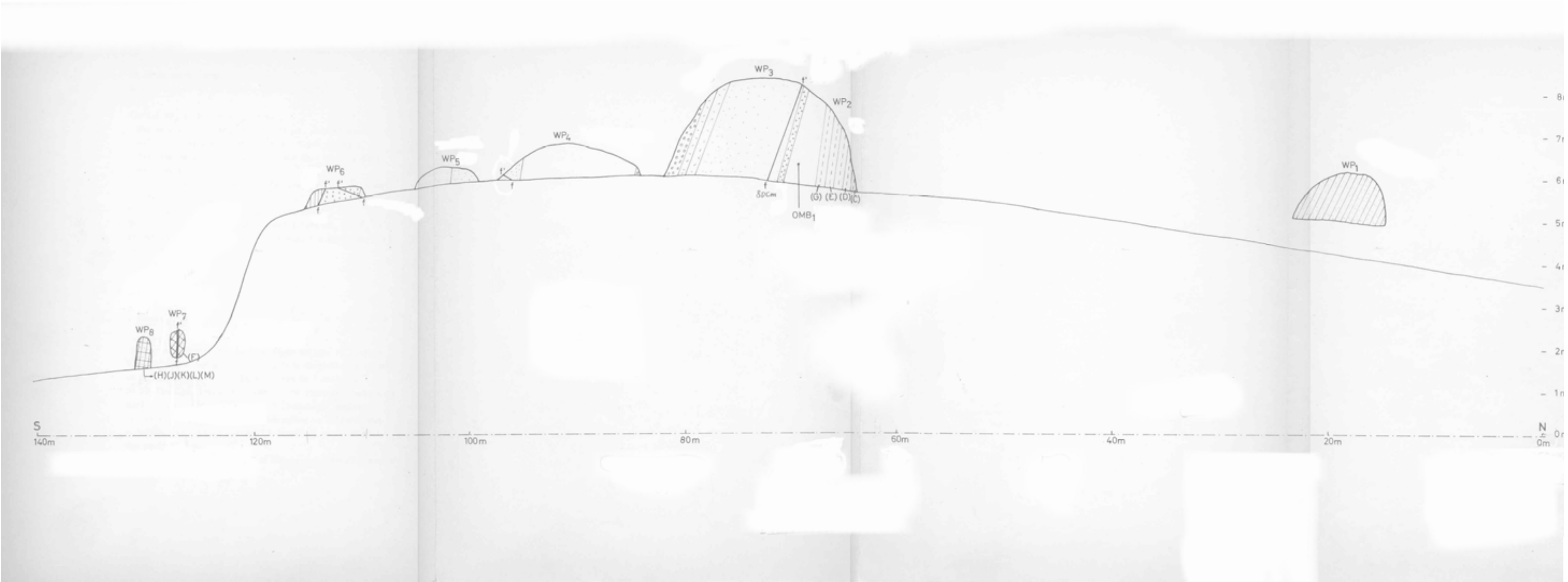
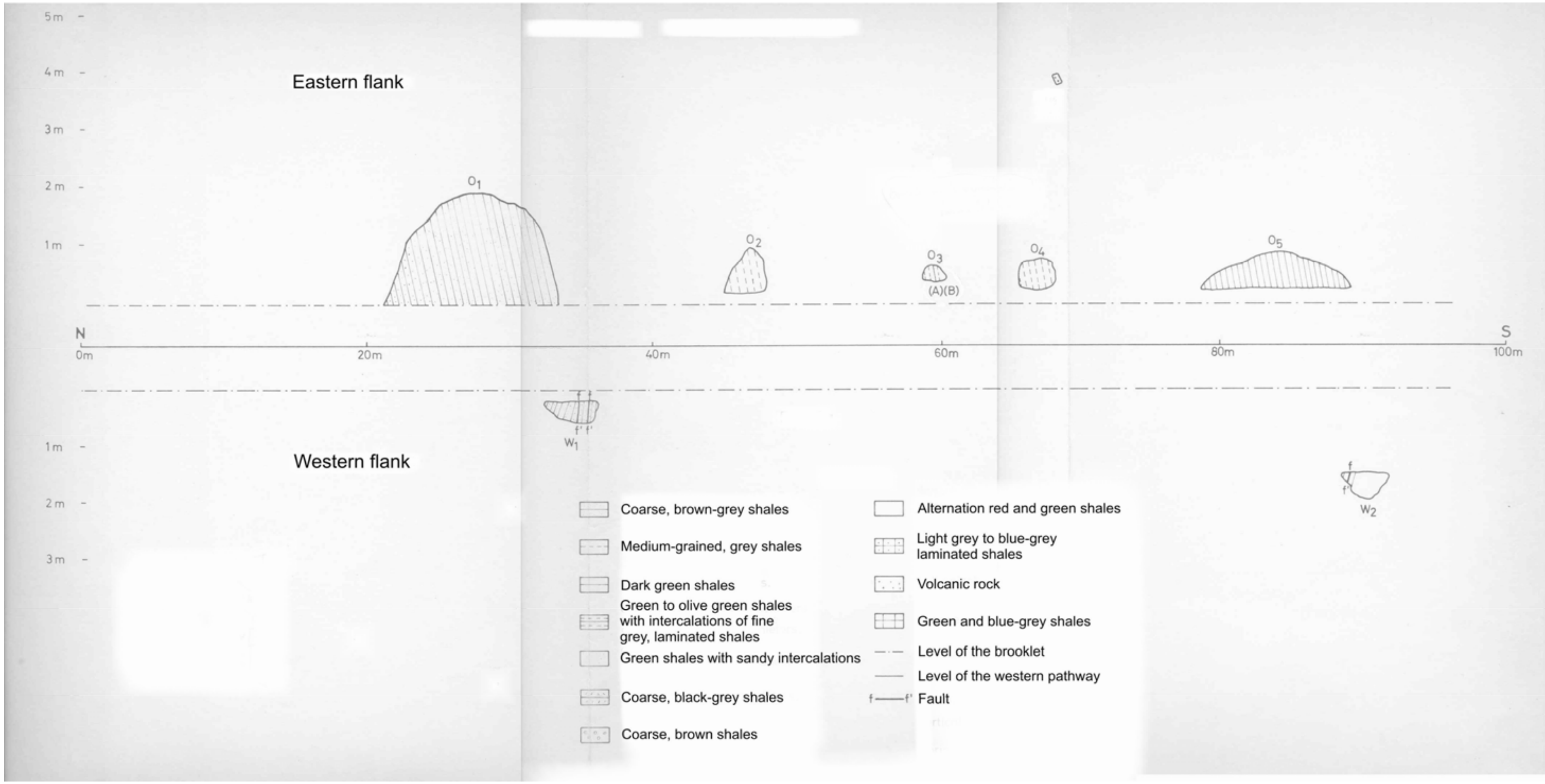


Fig. II.6.1. Section of Neuville-sous-Huy, ravine 1200 m east along the western pathway (this page) and along the brooklet (next page) according to Maes (1976). Modified from Maes (1976).



5 m
4 m
3 m
2 m
1 m
Eastern flank
O1
O2
O3
(A)(B)
O4
O5
N
S
0m
20m
40m
60m
80m
100m
f
f'
W1
1 m
2 m
3 m
Western flank
W2
Coarse, brown-grey shales
Medium-grained, grey shales
Dark green shales
Green to olive green shales with intercalations of fine grey, laminated shales
Green shales with sandy intercalations
Coarse, black-grey shales
Coarse, brown shales
Alternation red and green shales
Light grey to blue-grey laminated shales
Volcanic rock
Green and blue-grey shales
Level of the brooklet
Level of the western pathway
Fault

Unit 5: Green to green-grey shale with on regular distances bands of sandy shale or sandstone. The boundary between unit 4 and unit 5 have been taken at the disappearance of the fine grey shale and at the first sandy bank. This unit has a minimal thickness of 35 meters.

Unit 5': Within unit 5 a 5.1 meters thick level occurs consisting of an alternation of green to olive green and red shales. These shales are fine-grained with no sandy levels.

Unit 6: Transitional unit between unit 5 and unit 7 with a minimal thickness of 1.2 meters.

Unit 7: Light grey to blue-grey, finely laminated shales with a minimal thickness of 1.5 meters.

He interprets the sequence to be normal with a southern dip between 40° and 78°. The total thickness of these units is approximately 100 meters. Possibly one large and multiple smaller faults are present.

Three volcaniclastic layers have been described, one more than Michot (1934) that didn't observe volcaniclastic layer V1. A description of these volcaniclastic layers is found in table II.7.2.

Twelve graptolite levels were described. Their graptolite content and their assignment into biozones is described in table II.6.1. The graptolites were identified by B. Rickards.

Graptolite level	unit	Graptolites	Graptolite Biozone
Graptolite levels H, J, K, L and M belong to the *centrifugus* Biozone when we look at the position of these levels.			
M	7	*Monograptus vomerina* s.l., *Monograptus vomerina* cf. *basilica*	?
L	7	*Monograptus priodon* s.l., *Monograptus vomerina* s.l., *Monograptus vomerina basilica*, *Monograptus vomerina* cf. *basilica*, *Monograptus griestoniensis* cf. *nicoli*, *Monograptus kolihai*, *Retiolites geinitzianus*, *Retiolites* cf. *geinitzianus*, *Retiolites geinitzianus angustidens*	*centrifugus* Biozone
K	7	*Monograptus vomerina* s.l., *Monograptus vomerina basilica*	*centrifugus* Biozone
J	7	*Monograptus priodon* s.l., *Monograptus vomerina* s.l., *Monograptus vomerina basilica*, *Monograptus vomerina* cf. *basilica*, *Monograptus* cf. *kodymi*, *Monoclimacis* sp., *Retiolites geinitzianus geinitzianus*	most probably *centrifugus* Biozone, although *crenulata* Biozone cannot be excluded
H	7	*Monograptus priodon* s.l., *Monograptus vomerina* cf. *basilica*, *Monoclimacis* sp.	?
F	6	*Monograptus vomerina* cf. *vomerina*, *Monograptus vomerina vomerina*, *Monograptus griestoniensis*, *Monograptus*? *singularis*, *Monograptus priodon* s.l., *Monograptus*	*crenulata* Biozone

		priodon, *Monograptus* cf. *crenulata* sensu Elles & Wood, *Monograptus*? *marri*, *Monograptus*? *rickardsi*, *Monograptus*? *cultellus*, *Monoclimacis* sp., *Pristiograptus nudus*, *Pristiograptus denenastiae*, *Pseudoplegmatograptus* sp., *Bryograptus pulchellus*, *Retiolites geinitzianus*, *Retiolites geinitzianus angustidens*	
G	4	*Monoclimacis* sp., *Monograptus* sp.	likely *crenulata* Biozone
E	4	*Monograptus priodon* s.l., *Monograptus spiralis*, *Monograptus* cf. *spiralis*, *Monograptus tullberei*, *Monograptus* cf. *crenulata* sensu Elles & Wood, *Monoclimacis*? *vomerina*, *Monoclimacis griestoniensis* s.l., *Pristiograptus nudus*, *Pristiograptus denastiae*, *Retiolites geinitzianus*	*crenulata* Biozone
D	4	*Monograptus spiralis*, *Monograptus* sp., *Monograptus*? *parapriodon*, *Monograptus*? *marri*, *Monograptus* cf. *crenulata* sensu Elles & Wood, *Pristiograptus nudus*	probably *crenulata* Biozone
C	4	*Monoclimacis* sp., *Monograptus priodon* s.l., *Monograptus spiralis*, *Monograptus*? *parapriodon*, *Retiolites geinitzianus*	likely *crenulata* Biozone
B	1	*Monograptus* cf. *marri*, *Monograptus rickardsi*, *Monograptus* cf. *gennatus*, *Monograptus exiguous*, *Monograptus rickardsi* s.s., ? *Monograptus barrandei*, *Climacograptus* cf. *nebula*	*turriculatus* Biozone
A	1	*Monograptus priodon* s.l., *Monograptus marri*, *Monograptus* cf. *marri*, *Mediograptus* sp. of *Streptograptus* sp., *Retiolites geinitzianus* s.l., *Rastites* sp.	upper-*turriculatus* Biozone

Table II.6.1. The twelve graptolite levels, their graptolite content by identifications of B. Rickards and their assignment into a biozone all in Maes (1976). The same numbering has been used as Vandevelde (1976). The assignment into biozones is according the scheme of Rickards (1976).

Maes (1976) saw that sediments of the *crispus* Biozone and the *griestoniensis* Biozone are missing although present in Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville (Vandevelde, 1976 and Maes *et al.*, 1978). Hence he concluded that there should be a big fault cutting away these sediments.

Maes (1976) studied one sample on acritarchs making a systematical inventory of the acritarch content. Vandevelde (1976) studied the chitinozoans of the same sample. But due to the poor knowledge of the stratigraphic distribution of the chitinozoans at that time no further information could be given.

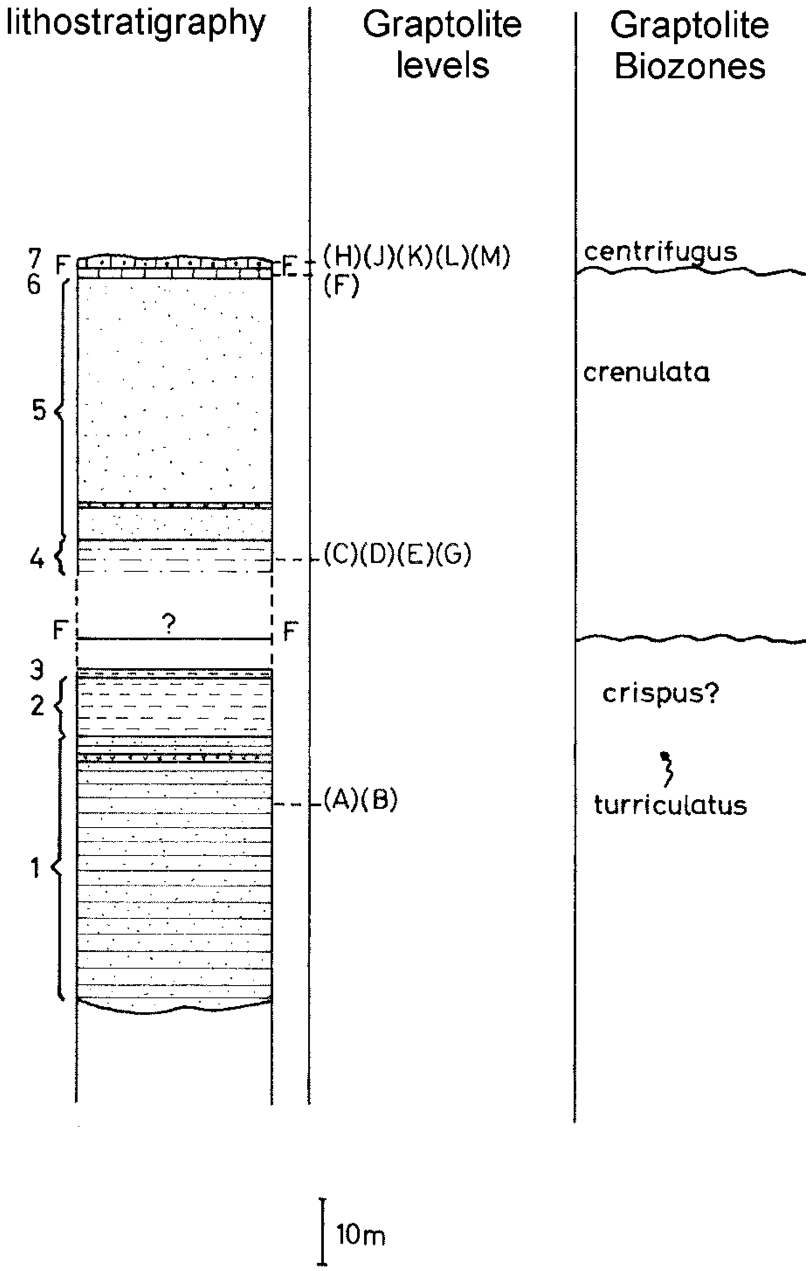


Fig. II.6.2. Litho-, bio-, and chronostratigraphy of the section Neuville-sous-Huy, ravine 1200 m east. Modified from Maes, 1976.

6.3. New data

see also fig. II.6.3

6.3.1. Lithological results

Outcrops are visible in the brooklet and along a pathway west of the brooklet in the western flank (see fig. II.6.4). The beds are almost always dipping to the southeast to south-southeast.

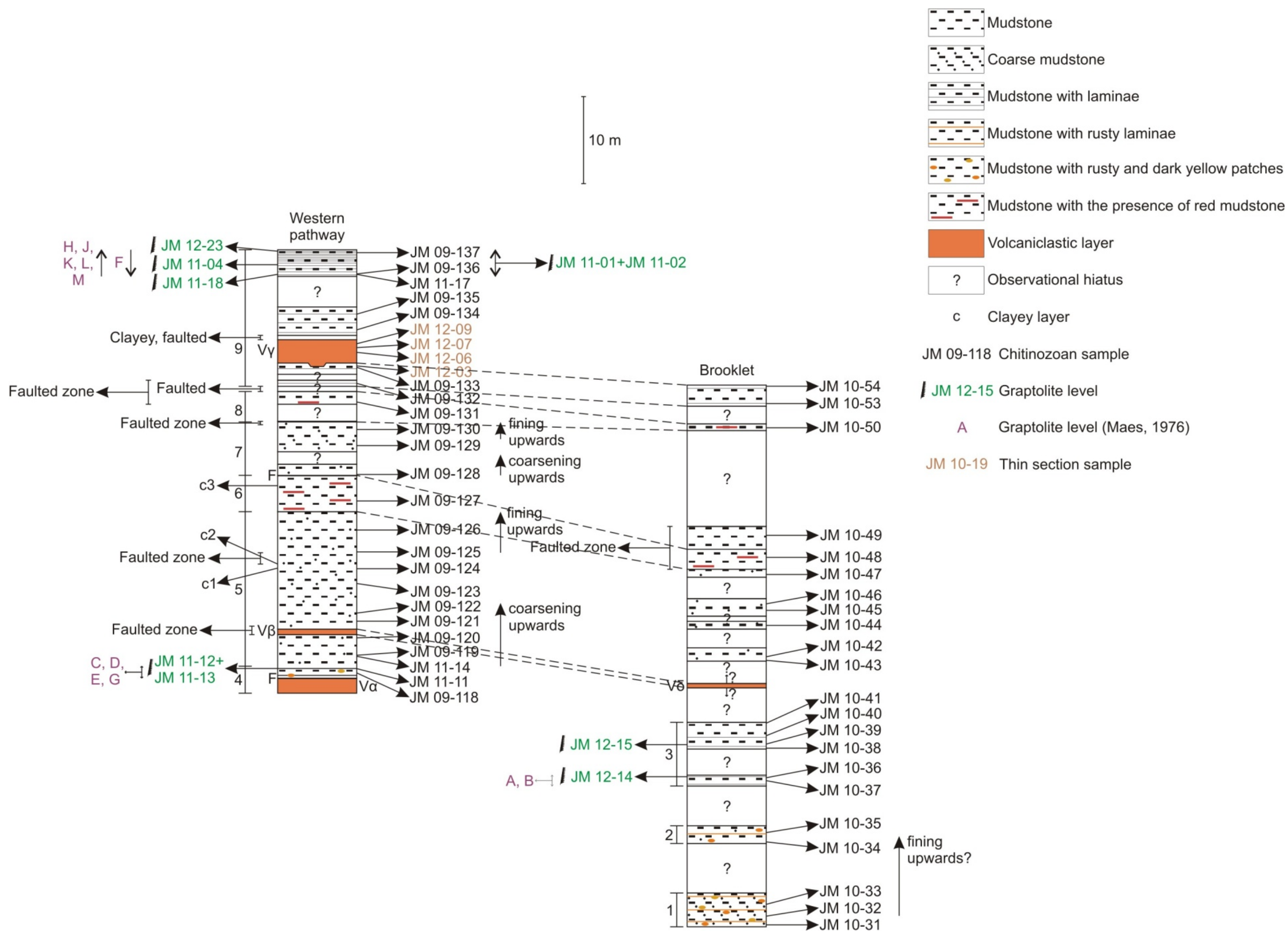


Fig. II.6.3. Litholog of the section Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville of the outcrops along the brooklet and the western pathway. A correlation is made between the outcrops of the western pathway and the outcrops along the brooklet.

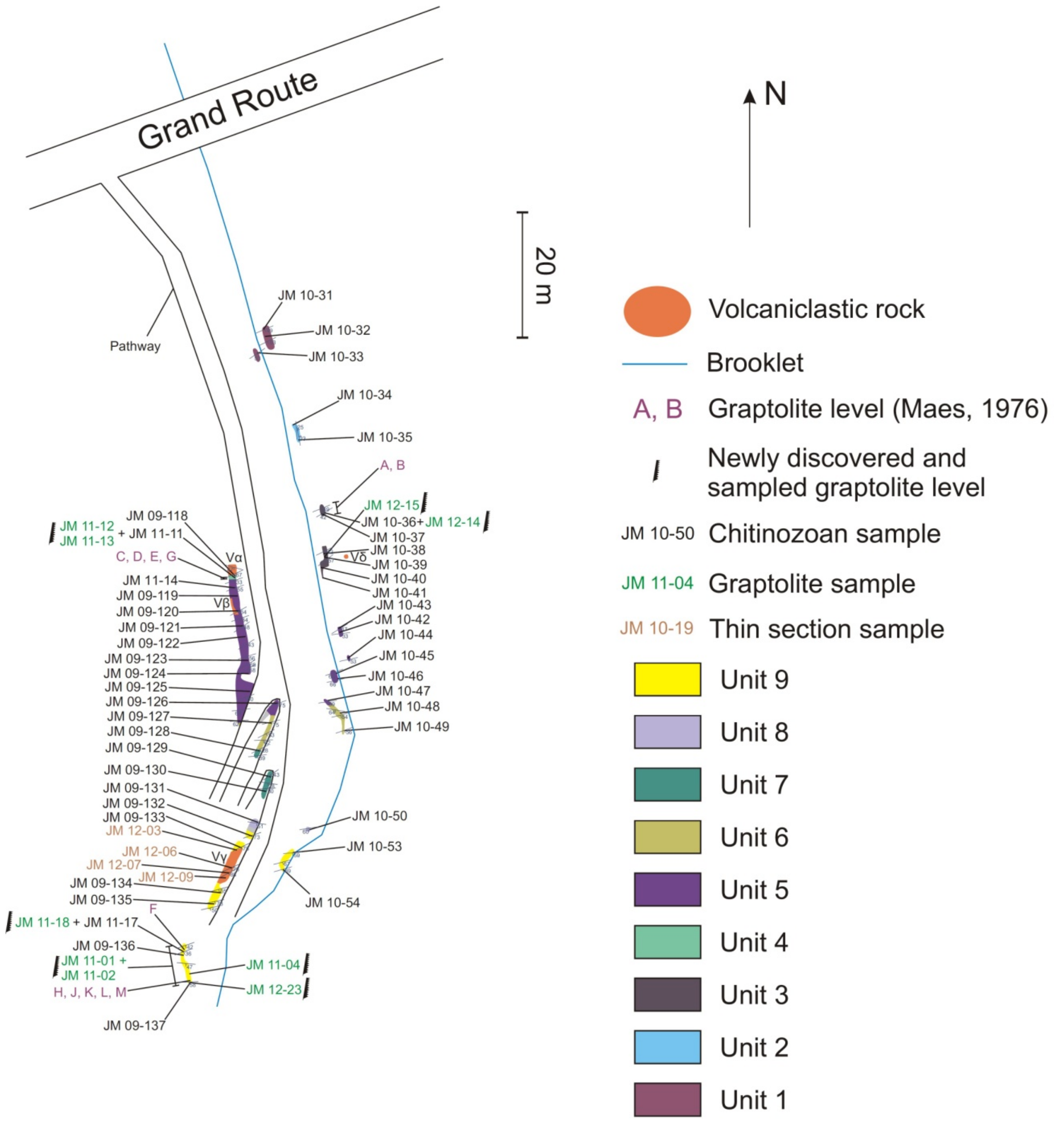


Fig. II.6.4. Map of the section Neuville-sous-Huy, ravine 1200 m east.

The section can be divided into 9 units. From north to south:

Unit 1: Laminated, grey, coarse to very coarse mudstone up to very fine sandstone with rusty and dark yellow laminae and rusty to dark yellow patches (mostly less than 1 mm up to 4 mm in length) orientated parallel to the bedding. The laminae are bounded to certain beds. The observed thickness is 3.9 meters.

Unit 2: Grey to dark grey mudstone, sometimes slightly coarser, with rusty patches and weakly laminated with rusty laminae. These rusty patches can be parallel and also oblique to the bedding. The observed thickness is 2 meters. Unit 2 is only present in one outcrop and the beds are dipping to the east in this outcrop.

Unit 3: Dark grey and green-grey mudstone, most of the time compact but sometimes laminated. In the laminated, dark grey levels graptolites occur. Sometimes the green colour in the mudstone is fainting and almost only a grey colour is present. Towards the top green-grey mudstone becomes more rare and grey to dark grey mudstone dominates. The thickness is estimated at 7.3 m.

Unit 4: Grey over olive green to green-grey, compact mudstone, interbedded with laminated beds of dark grey and green-grey mudstone. In these laminated beds graptolites occur in the dark grey mudstone. Rusty to dark yellow patches (mostly less than 1 mm in length and rarely up to 3 mm long) orientated parallel to the bedding can occur and are bounded to certain beds. There is a gradual transition between unit 4 and unit 5. The boundary has been taken at the first coarser level. This unit contains one volcaniclastic layer, Vα. The observed thickness (minimal) is 3.1 m.

Unit 5: Grey to dark grey, olive green to green-grey mudstone up to coarse mudstone. But in general mudstone occur with faint centimetric banks of coarser mudstone up to coarse mudstone. The greenish colour is only present in the finer mudstone. The beds are sometimes weathered to a more reddish colour. One volcaniclastic layer is present in this unit, Vβ. A coarsening upwards is observed in unit 5. Higher up in unit 5 a fining upwards is observed going with a gradual transition into unit 6. The thickness of this unit is 17.8 m.

Unit 6: Decimetric, mostly centrimetric to millimetric alternation of red mudstone and green to olive green and dark grey mudstone. The base of the unit has been taken at the base of the first level of red mudstone. Above and close to the base rare millimetric beds occur of medium-grained mudstone. The green colour is more frequently present in unit 6 in comparison with unit 5. The observed thickness is 4.2 m.

Unit 7: Grey to dark grey, olive green, green-grey, grey-green to green mudstone with, sometimes clearly present, centimetric beds of coarse to very coarse mudstone up to very fine sandstone. The green colour is only present in the finer part. A coarsening upwards is observed in the lower part and higher in the unit a fining upwards is observed. The thickness is estimated at 6.1 m.

Unit 8: Green to olive green mudstone with at the base red mudstone. The appearance of red mudstone have been used to define the base of the unit. The outcrops with this unit are poor, probably caused by the presence of faults. The stratigraphical contact between unit 8 and unit 9 is not observed, probably because of the presence of a fault. The thickness is estimated at 3.5 m.

Unit 9: Dark grey to dark green-grey mudstone. The frequency of the laminations becomes higher towards the top although compact beds still occur. These laminations are most clearly present in the most southern outcrop. In this outcrop mudstone occurs that is compact over some laminations present in the mudstone to finely laminated mudstone. There is a tendency of lamination higher in the unit. The green colour tends to disappears going upwards. The finely laminated mudstone is interpreted as laminated hemipelagites. This unit contains one volcaniclastic layer, Vγ. The thickness is estimated at 15.7 m.

6.3.2. Clay layers

There are a total of three clay layers present (see fig. II.6.3), two in unit 5 (c1 and c2) and one in unit 6 (c3). They are almost parallel with the bedding of the neighbouring rock. The first layer, c1, is varying in thickness (mostly 4 cm thick). No clear white layer is present but it is always white grey. But clearly faults have been developed and affected this weak zone. The second layer, c2, is also varying in thickness (between 4,5 and 8,5 cm thick). In c2 a more clearly white layer has been formed but a fault has been developed in this weak zone and clearly affecting this layer. The third layer, c3, has a thickness of approximately 1.2 cm, sometimes a little bit thinner. Most of the time it is brownish but white clay has also been observed. It is affected by weakly south dipping faults.

Faults have been developed in all the clay layers making the interpretation of these layers more difficult. The clay layers are almost always parallel with the bedding of the neighbouring rock. But the thickness is not always constant and white clay is not always clearly present. These clay layers have a possible volcaniclastic origin but further analyses are necessary to prove this hypothesis.

6.3.3. Tectonic deformation

Fig. II.6.5. The northdipping fault between unit 6 and unit 7. Unit 6 becomes more and more fractured when approaching the fault.

Faults are present in the section hampering a continuous record of the sedimentation. Hence the thicknesses of the different units are an estimation. Although in many cases along the faults a centimetric, decimetric or metric movement has been observed indicating that the record of the sediments are quite continuous. The places where faults are found with a larger movement (or the movement could not be determined) are indicated on the litholog (see fig. II.6.3).

In almost all the cases the faults have a southern dip and consists of two types: weakly dipping faults and steeply dipping faults. In one place a steeply north dipping fault, Strike 277/ Dip 79N, has been observed: the boundary between unit 6 and unit 7 (see fig. II.6.5).

In the outcrop where unit 2 is present an exception to a southern bedding has been found. In this outcrop the bedding is to east. This indicates the possible presence of a fault near this outcrop.

At the top of unit 3, almost in the bedding of the brooklet, small quartz veins are present, indicating the presence of a fault nearby. However this fault is not observed.

6.3.4. Chitinozoan results

see also fig. II. 6.6

A total of 45 samples were studied giving a total of 1263 studied chitinozoans (see also table II.6.2). Twelve samples are barren. The chitinozoans are in general poorly preserved. But exceptions are present in this general trend of preservation without any apparent reason for it. In unit 1 the chitinozoans are moderately well preserved. In sample JM 10-41 the chitinozoans are poorly to moderately well preserved. Sample JM 09-126 contain moderately well to well preserved chitinozoans. This is surprising because absolutely no reason (lithology, presence of faults, change of sample position) is found for this kind of preservation and the samples below and above contain poorly preserved chitinozoans.
The abundance of the chitinozoans is generally low and most of the time less than 0.50 chitinozoans per gram of rock. Only 11 samples contain more than 0.50 chitinozoans per gram of rock with one peak of 21.17 chitinozoans per gram of rock for sample JM 09-126. The abundance of the three samples of unit 1 are higher with a maximum of 4.88 chitinozoans per gram of rock in sample JM 10-33. Samples JM 11-11 and JM 11-14 have been taken in graptolite levels and the abundance of these samples are a bit higher (but still less than 2 chitinozoans per gram of rock). Sample JM 10-41 have been taken almost in the brooklet where the rock was still very fresh. This is likely the reason for the higher abundance of it (1.81 chitinozoans per gram of rock). Although this is not always the case because samples JM 10-53 and JM 10-54 have been taken also at almost the level of the brooklet. These two samples contain almost no chitinozoans although the rock was very fresh and almost not weathered. Hence other causes have been searched for the low abundances in these two samples but these are still unknown.

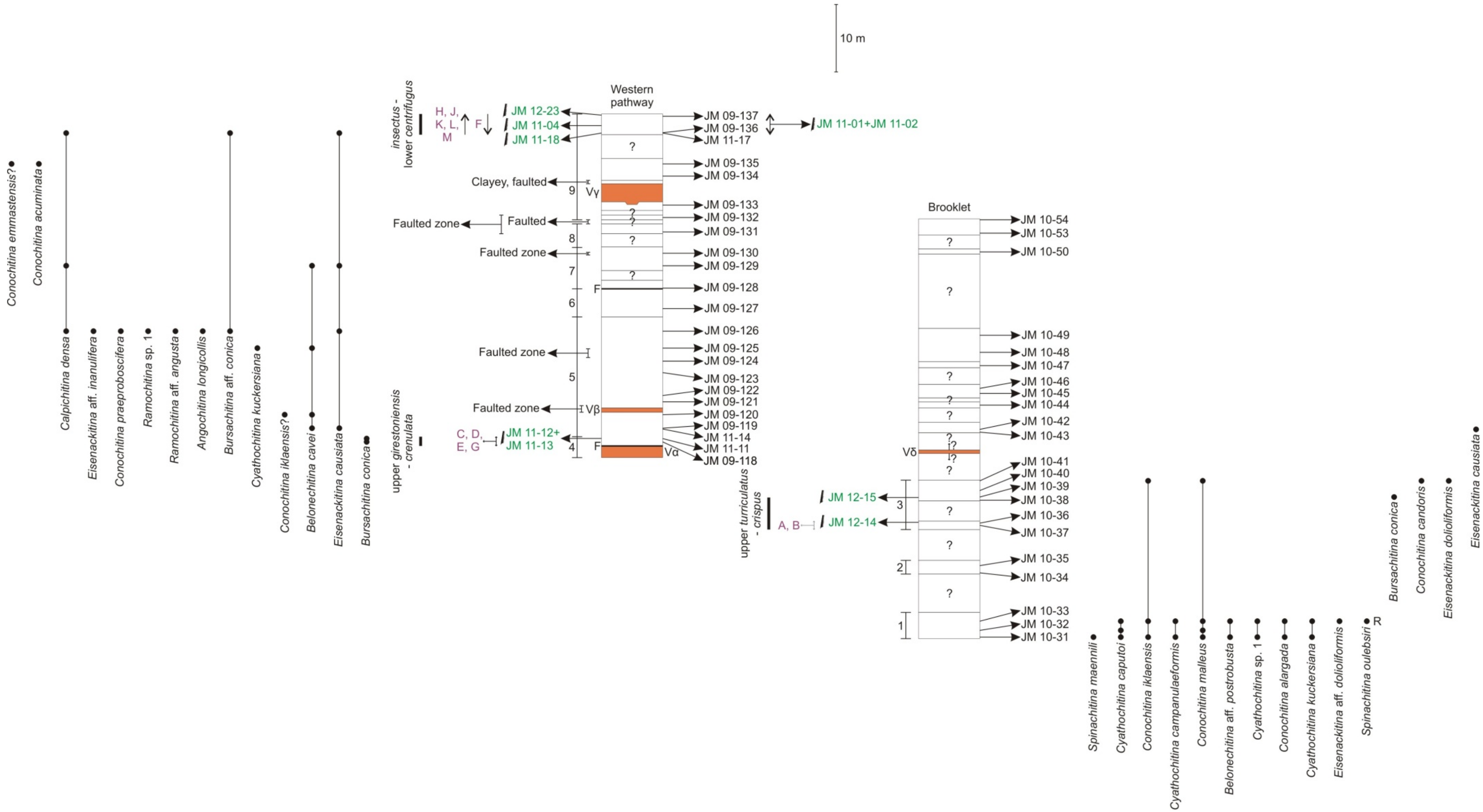


Fig. II.6.6. Litholog of the section Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville with the distribution of the chitinozoans throughout the section together with the graptolite biozonation.

	Unit	Sample number	*Ancyrochitina* spp.	*Belonechitina* spp.	*Bursachitina conica*	*Bursachitina* spp.	*Desmochitina* spp.	*Calpichitina* spp.	*Conochitina* spp.	*Sphaerochitina* spp.	*Spinachitina* spp.	*Eisenackitina causiata*	*Belonechitina cavei*	*Conochitina iklaensis?*	*Cingulochitina* spp.	*Cyathochitina kuckersiana*	*Cyathochitina* spp.	*Bursachitina* aff. *conica*	*Angochitina longicollis*	*Ramochitina* aff. *angusta*	*Ramochitina* sp. 1	*Conochitina praeproboscifera*	*Calpichitina densa*	*Eisenackitina* aff. *inanulifera*	*Angochitina* spp.	*Ramochitina* spp.	*Eisenackitina* spp.	*Fungochitina* spp.	*Conochitina acuminata*	*Conochitina emmastensis?*	*Spinachitina maennili*	*Spinachitina oulebsiri*	*Conochitina alargada*	*Conochitina iklaensis*	*Conochitina malleus*	*Cyathochitina campanulaeformis*	*Cyathochitina caputoi*	*Belonechitina* aff. *postrobusta*	*Cyathochitina* sp. 1	*Tanuchitina* spp.	*Eisenackitina* aff. *dolioliformis*	*Eisenackitina dolioliformis*	*Conochitina candoris*	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
Brooklet	9	JM 10-54																																									0	35.85	0.00
		JM 10-53							1																																	1	2	35.75	0.06
	8	JM 10-50																																									0	35.61	0.00
	6?	JM 10-49	2						1																1																			9	13	35.24	0.37
	6	JM 10-48		2					1																																	2	5	35.03	0.14
	5	JM 10-47																																								4	4	33.73	0.12
		JM 10-46					1		1																																	6	8	35.05	0.23
		JM 10-45																																									0	35.28	0.00
		JM 10-44							1																																	5	6	35.09	0.17
		JM 10-42		1			2		1	3		1																														5	13	34.94	0.37
		JM 10-43					1																																			4	5	35.32	0.14
	3	JM 10-41	4			1			5	3	3																							1	1							1	2	43	64	35.32	1.81
		JM 10-40	1						1																																	8	10	35.57	0.28
		JM 10-39	4		1	2																																				7	14	20.24	0.69
		JM 10-38																																									0	35.50	0.00
		JM 10-36																																								1	1	35.47	0.03
		JM 10-37	1																																							3	4	35.20	0.11
	2	JM 10-35		1			1		2		1																															1	6	35.54	0.17
		JM 10-34		1					1		1																															5	8	35.16	0.23
	1	JM 10-33	3	17		1	3		17	4	15					2	1										6					1	3	5	1	6	5	1	2	1	1			73	168	34.44	4.88
		JM 10-32		10					11	2	4						1								1		2								2		3			2				53	91	35.56	2.56
		JM 10-31	2	20		6	2		18	3	22					1	5										6				2		1	5	4	1	3	3	2	1				62	169	35.48	4.76
Path	9	JM 09-137																																									0	34.73	0.00
		JM 09-136																																								1	1	33.64	0.03
		JM 11-17	20	2						4		2						1					2		4	40		1																50	126	40.58	3.10

		JM 09-135							2																		1		2	1														4	10	32.18	0.31
		JM 09-134																																											0	31.48	0.00
		JM 09-133																																											0	32.12	0.00
		JM 09-132																																											0	33.15	0.00
	8	JM 09-131																																											0	31.57	0.00
		JM 09-130																																											0	30.53	0.00
	7	JM 09-129	1	3					3			1	1		1								2				1																	20	33	30.42	1.08
		JM 09-128																																											0	30.38	0.00
	6	JM 09-127																																										1	1	33.28	0.03
		JM 09-126	18	10		2			5			4					1	2	38	20	7	1	3	1	112	24	5	5																71	329	31.08	10.59
		JM 09-125					1						1			1	1																											11	15	30.90	0.49
		JM 09-124																																											0	30.89	0.00
		JM 09-123													1																													3	4	31.01	0.13
	5	JM 09-122																																										2	2	31.14	0.06
		JM 09-121																																											0	30.18	0.00
		JM 09-120		1					2				1	1																														9	14	32.56	0.43
		JM 09-119	1			2	1	1	2		1	1	1																															13	23	32.47	0.71
		JM 11-14	2			1	2	1	7	1																																		41	55	32.30	1.70
	4	JM 11-11			6	6																																						38	50	42.25	1.18
		JM 09-118	2	2	1																																							4	9	67.12	0.13
Total			61	70	8	21	14	2	82	20	47	9	4	1	2	4	9	3	38	20	7	1	7	1	118	64	21	6	2	1	2		4	11	8	7	11	4	4	4	1	1	2	560	1262	1546.33	0.82

Table II.6.2. Chitinozoan results of Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville. Note that from sample JM 09-126 only 50 % is counted.

The samples in the flanks of the brooklet are taken 6 to 8 meters topographically lower in comparison with the samples in the western flank of the pathway. We would expect a better preservation for the samples taken in the flanks of the brooklet in comparison with these from the pathway but this is not the case. Hence other reasons have to be searched for this difference but these are still unknown.

Due to the poor preservation state of the chitinozoans in many samples ranges of the chitinozoans cannot be used or have to be treated by caution.

In unit 1 the diversity of the chitinozoans is high. We could identify *Spinachitina maennili*, *S. oulebsiri*, *Conochitina malleus*, *C. iklaensis*, *C. alargada*, *Cyathochitina caputoi*, *C. kuckersiana*, *C. campanulaeformis*, *Cyathochitina* sp. 1 and *Belonechitina* aff. *postrobusta*.

In unit 2 the chitinozoans could be identified to the generic level only.

Unit 3 contains the following chitinozoans: *Conochitina iklaensis*, *C. malleus*, *C. candoris*, *Eisenackitina dolioliformis* and *Bursachitina conica*.

In unit 4 we identified *Bursachitina conica*.

Unit 5 contains at the base *Eisenackitina causiata* and *Belonechitina cavei*. One rich chitinozoan sample, JM 09-126, occurs containing *Angochitina longicollis*, *Conochitina praeproboscifera*, *Calpichitina densa*, *Ramochitina* aff. *angusta*, *Bursachitina* aff. *conica* and *Ramochitina* sp. 1 and also *Eisenackitina causiata*.

Unit 6 contains only chitinozoans identifiable to generic level.

Only one of the three samples of unit 7, JM 09-129, contain chitinozoans: *Eisenackitina causiata*, *Belonechitina cavei* and *Calpichitina densa*.

In unit 8 no chitinozoans could be recovered from the two samples.

Nine samples have been studied from unit 9 and four of them contain chitinozoans. In JM 09-135 *Conochitina acuminata* occurs. Sample JM 11-17 contains *Calpichitina densa*, *Eisenackitina causiata* and *Bursachitina* aff. *conica*. Interesting to note in sample JM 11-17 is the dominance of the two genera *Ramochitina* spp. and *Ancyrochitina* spp. making together 47.6 % of the total chitinozoan assemblage. But due to their poor state of preservation no further identification is possible.

Systematics of the chitinozoans

Incertae sedis group Chitinozoa Eisenack, 1931

Order Prosomatifera Eisenack, 1972

Family Conochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Conochitinae Paris, 1981

Genus *Conochitina* Eisenack, 1931 emend. Paris *et al.*, 1999

Conochitina emmastensis?

Material: 1 broken specimen from JM 09-135.

Dimensions: L: >177 µm (n=1); Dp: 90 µm (n=1).

Description: we refer for the description to Nestor, 1982a & 1994.

Discussion: The only recovered specimen is broken, hence the use of open nomenclature.

Conochitina iklaensis?

Plate II.6.1., specimen 1

Material: 1 broken specimen from JM 09-120.

Dimensions: L: >169 µm (n=1); Dp: 61 µm (n=1).

Description: we refer for the description to Nestor, 1980a & 1994.

Discussion: The only recovered specimen is broken, hence the use of open nomenclature.

Subfamily Belonechitininae Paris, 1981

Genus *Belonechitina* Jansonius, 1964

Belonechitina aff. *postrobusta*

Plate II.6.3., specimen 16

Material: 3 specimens from JM 10-31, 1 specimen from JM 10-33.

Dimensions: L: >200-216-245 µm (n=4); Dp: 79-85-90 µm (n=4); Dc: ≤51-63-70 µm (n=4).

Description: we refer for the description to Nestor, 1980b & 1994 and below in discussion.

Discussion: The species displays the characteristics of *Belonechitina postrobusta* except for the different ornamentation. *Belonechitina postrobusta* has always short, little spines or verrucae with a multipodal base. Our specimens have granules without the multiple roots. More specimens in samples JM 10-31, JM 10-32 and JM 10-33 have many characteristics of the species, but were not included because they have other characteristics making them different.

Family Lagenochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Cyathochitinae Paris, 1981

Genus *Cyathochitina* Eisenack, 1955b emend. Paris *et al.*, 1999

Cyathochitina sp. 1

Plate II.6.4., specimen 15, 16

Material: 2 specimens from JM 10-31, 2 specimens from JM 10-33.

Dimensions: L: 230-261-315 µm (n=4; with broken necks); Dp: 98-115-130 µm (n=4); Dc: 49-60-69 µm (n=4).

Description: The chamber of the species is of a considerable length. The lower part of the chamber (towards the base) is subcylindrical and passes into a conical form upwards towards the apertural pole narrowing the chamber. The smallest width is reached at the base of the neck and the neck widens slightly going to the apertural pole. The base is concave and wears a short carina.

Discussion: The species is different from *Cyathochitina calix* (Eisenack, 1931), which has a strictly conical. The form of the chamber of *Cyathochitina* sp.1 is in the lower part subcylindrical changing upwards towards the apertural pole into a conical form.

Subfamily Angochitininae Paris, 1981

Genus *Ramochitina* Sommer & van Boekel, 1964

Ramochitina aff. *angusta*

Plate II.6.1., specimens 14-16

Material: 20 specimens from JM 09-126.

Dimensions: L: 163-181-221 µm (n=8); Dp: 60-73-85 µm (n=20); Dc: 21-34-43 µm (n=15).

Description: The species has an oval chamber passing into a neck with a length approximately the same length of the chamber or shorter. The neck can widen towards the aperture. The vesicle is often curved. Longitudinal ridges are often present with spines developed on them. The longitudinal ridges can be absent but often the alignment of spines is still present. The alignment of the spines on the vesicle is sometimes not so obvious but can be on other places very clear.

Discussion: The species has a form between *Angochitina longicollis* (Eisenack, 1959) and *Ramochitina angusta* (Nestor, 1982b) as it possesses characteristics of both species. The spines have the same size and form as these from *Angochitina longicollis* while the spines of *Ramochitina angusta* are bigger. The spines are aligned (sometimes unclear), hence an attribution to the genus of *Ramochitina* is correct. The similarity of the vesicle shape of *Ramochitina angusta* and *Angochitina longicollis* has already been noted by Nestor (1982b, 1994). *Ramochitina angusta* has been distinguished from *Angochitina longicollis* by the type of ornamentation, the form and the length of the spines. Our specimens fall in between these two species.

Ramochitina sp. 1

Plate II.6.2., specimens 1-3

Material: 7 specimens from JM 09-126.

Dimensions: L: 120-143-155 (n=5); Dp: 75-85-98 µm (n=7); Dc: 27-33-35 µm (n=5).

Description: The species has a globose body and a neck widening to the aperture. The chamber has a subspherical form with a convex base. The maximal width of the chamber can be, but not always, slightly lower than the middle of the chamber. The vesicle is ornamented with longitudinal ridges where upon the spines develop. Next to the longitudinal ridges with spines the vesicle can be ornamented with granules.

Discussion: The species is distinguished from *Ramochitina aff. angusta* because the form of the chamber is more spherical and the length of the neck is always shorter than that of the chamber.

Order Operculatifera Eisenack, 1931

Family Desmochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Desmochitininae Paris, 1981

Genus *Bursachitina* Taugourdeau, 1966 restrict. Paris, 1981

Bursachitina aff. *conica*

Plate II.6.1., specimens 4, 5

Material: 2 specimens from JM 09-126, 1 specimen from JM 11-17.

Dimensions: L: 363-382 µm (n=2); Dp: 198 µm (n=1); Dc: 118 µm (n=1).

Description: The species has a thick wall and almost a flat base with a rounded basal edge. It has slightly convex flanks passing into a small neck with the presence of a flexure. The vesicle wall is smooth. The vesicle is sealed by an operculum.

Discussion: The dimensions of the specimens are too large to be included into *Bursachitina conica*. Also the presence of a flexure and a neck hampers the identification to include the specimens into *Bursachitina conica*.

Subfamily Eisenackitininae Paris, 1981

Genus *Eisenackitina* Jansonius, 1964 restrict. Paris, 1981

Eisenackitina aff. *inanulifera*

Plate II.6.2., specimen 4

Material: 1 specimen from JM 09-126.

Dimensions: L: 126 µm (n=1); Dp: 85 µm (n=1); Dc: 45 µm (n=1).

Description: we refer for the description to Nestor, 2005.

Discussion: The only difference between our specimen and *Eisenackitina inanulifera* is the ornamentation. Our specimen has ridges (parallel with the length of the species) with little spines on it causing a lined ornamentation. *Eisenackitina inanulifera* has never ridges and a felt-like, rugose or finely granulated ornamentation.

Eisenackitina aff. *dolioliformis*

Material: 1 specimen from JM 10-33.

Dimensions: L: 212 µm (n=1); Dp: 120 µm (n=1).

Description: we refer for the description to Umnova, 1976 and additional description to Nestor, 1994.

Discussion: The ornamentation is the only difference between our specimen and *Eisenackitina dolioliformis*. Our specimen has fine granules, very densely placed on the vesicle wall. *Eisenackitina dolioliformis* has coarse granules to tubercules that are never densely placed (they do not touch each other).

Discussion on bio- and chronostratigraphy with chitinozoans

We have subdivided the chitinozoan results by the units where they are present.

Unit 1

As indicated above many chitinozoan species do occur in this unit. There are three stratigraphically important species: *Spinachitina maennili*, *Conochitina alargada* and

Conochitina malleus. *Spinachitina maennili* defines a biozone globally (Verniers *et al.*, 1995) and on eastern Baltica (Nestor, 2012). The biozone is situated globally and on eastern Baltica from the upper to uppermost Rhuddanian to the lower Aeronian. But this species ranges from the upper to uppermost Rhuddanian to the lower part of the upper Aeronian globally and on Baltica. *Conochitina alargada* defines the succeeding biozone (Verniers, 1995 & Nestor, 2012) and is situated from the lower Aeronian to the upper Aeronian. It has a range in Baltica from the lower-middle Aeronian to the end of the Aeronian. *Conochitina malleus* occurs higher in the *Conochitina alargada* Biozone (Nestor, 2012) from the upper part of the middle Aeronian to the lower Telychian (so until the succeeding biozone). It is considered as a biozone in some East Baltic drill cores between the *Conochitina alargada* Biozone and the *Eisenackitina dolioliformis* Biozone (Nestor *et al.*, 2003). When we take these results together it means that we are in the upper part of the *Conochitina alargada* Biozone due to the presence of *Conochitina malleus*. But *Spinachitina maennili* is still present. It means that unit 1 ranges from the upper part of the middle Aeronian to the lower part of the upper Aeronian. The other chitinozoans that are present in this unit do not contradict this age assignment. The occurrence of one specimen of *Spinachitina oulebsiri* in sample JM 10-33 is caused by reworking.

Unit 2

The poor preservation of the chitinozoans do not allow to assign this unit to a certain biozone.

Unit 3

In one sample of this unit (JM 10-41) *Eisenackitina dolioliformis* and *Conochitina malleus* occur. As indicated above, on Baltica (Nestor, 2012) *Conochitina malleus* ranges up to the lower Telychian into the *Eisenackitina dolioliformis* Biozone. As we have *Eisenackitina dolioliformis* which starts to occur in the lower Telychian, it means that this sample, and probably also this unit, can be correlated with the lower Telychian. The other chitinozoans do not contradict this.

Unit 4

In unit 4 the only chitinozoan that could be determined to species level is *Bursachitina conica*. It starts low in the *Eisenackitina dolioliformis* Biozone (lower Telychian; Mullins & Loydell, 2001, Loydell *et al.*, 2010, Nestor, 2010). The uppermost occurrence of this species is not so clear. Loydell *et al.* (2010) have placed the last occurrence in the Kolka-54 core (Latvia) in the lower part of the *acuminata* Biozone (Upper Telychian); Nestor (2010) saw in the Viki Drill Core (Estonia) the last occurrence in the middle part of the *longicollis* Biozone (middle Telychian); Mullins & Loydell (2001) have in the Banwy River section (Wales) found as last occurrence certainly the upper *Margachitina margaritana* Biozone (lower Sheinwoodian) and possibly until the *Salopochitina bella* Biozone (middle Sheinwoodian); Nestor (2005) found that the species occur until the boundary of the *Margachitina margaritana* Biozone and the *Cingulochitina bouniensis* Biozone (lower Sheinwoodian). Hence we can conclude that unit 4 belongs to the Telychian up to certainly lower and possibly middle Sheinwoodian.

Unit 5

In unit 5 in sample JM 09-119 *Eisenackitina causiata* and *Belonechitina cavei* occurs. *Eisenackitina causiata* starts to occur low in the *Eisenackitina dolioliformis* Biozone (lower Telychian) and was found by Verniers (1999) until the middle Sheinwoodian. *Belonechitina cavei* has a much narrower range and starts in the middle of the *Eisenackitina dolioliformis* Biozone (lower to middle Telychian) and has his last appearance in the upper part of the *Angochitina longicollis* Biozone (middle Telychian). It means that from this sample on the unit can be certainly correlated with the range of *Belonechitina cavei*. This species has also been found in samples JM 09-120 and JM 09-125. One specimen of *Cyathochitina kuckersiana* occurs in JM 09-125. But the specimen is not well preserved, but still determinable, and hence possibly reworked.

In the highest sample of unit 5, JM 09-126 the sample with the highest abundance of the whole section, several chitinozoans occur that give us more information about the age. The most important chitinozoan is *Angochitina longicollis* as it defines a biozone in Baltica (Nestor, 2012) and globally (Verniers *et al.*, 1995). It starts to appear in the middle Telychian and ranges up to the lower Sheinwoodian in Baltica and globally. *Conochitina praeproboscifera* starts to occur in some East Baltic drill cores already in the underlying *Eisenackitina dolioliformis* Biozone. The highest occurrence of this species in these cores is at the top of the *Angochitina longicollis* Biozone (Loydell & Nestor, 2005; Loydell *et al.*, 2003 & 2010; Nestor, 2010) corresponding to the middle to upper Telychian. Interesting to note is that Mullins & Loydell (2001) has found that *Conochitina praeproboscifera* occurs until the base of the upper Telychian. JM 09-126 belongs to the *Angochitina longicollis* Biozone of the middle Telychian although a slightly younger age up to the base of the upper Telychian cannot be excluded.

These results show that unit 5 ranges from the middle of the *Eisenackitina dolioliformis* Biozone (lower to middle Telychian), into the *Angochitina longicollis* Biozone (middle Telychian). It is possible that it ranges up to the base of the upper Telychian.

Unit 6

The chitinozoans could not be determined to a species level, not allowing to place the unit into a biozone.

Unit 7

Only one sample, JM 09-129, contains chitinozoans. *Belonechitina cavei* starts to occur in the middle part of the *Eisenackitina dolioliformis* Biozone until the upper part of the *Angochitina longicollis* Biozone in eastern Baltica (Nestor, 2012). Hence this sample can be situated in the middle Telychian based on the occurrence of *Belonechitina cavei*. The presence of *Calpichitina densa*, which has a much longer range, does not contradict this.

Unit 8

No chitinozoans have been recovered from this unit, not allowing to place the unit into a biozone.

Unit 9

In sample JM 09-135 *Conochitina acuminata* is present and this species occurs from the upper Telychian (starting higher than *Conochitina proboscifera*) up to the Llandovery-Wenlock boundary (the exact level of this boundary is still not established) in eastern Baltica (Nestor, 2012). Hence sample JM 09-135 has the same range as *Conochitina acuminata*.

The uppermost sample of the unit, where chitinozoans identifiable up to species level occur, is JM 11-17 with *Calpichitina densa* and *Eisenackitina causiata*. *Calpichitina densa* has already been found in the lower to middle Telychian by Mullins & Loydell (2001) and occurs until the middle Sheinwoodian by the same authors (and also globally by Verniers *et al.*, 1995). The range of *Eisenackitina causiata* has already been discussed above. Hence we can conclude that JM 11-17 ranges from the lower to middle Telychian until the middle Sheinwoodian.

6.3.5. Graptolite results

Graptolites occur in unit 3 (4 levels), unit 4 (6 levels) and unit 9 (11 levels). The graptolites as described by Maes (1976) and Maes *et al.* (1978) were also reidentified. The graptolites are studied and identified by Prof. Dr. Petr Storch (Institute of Geology AS CR, Prague, Czech Republic). The results of the identifications and the resulting biozonation is given in table II.6.3.

The graptolite levels A, B, JM 12-14 and JM 12-15 occurring in unit 3 belong to the upper *turriculatus* to *crispus* Biozone of the lower Telychian. The graptolite levels C, D, E, G, JM 11-12 and JM 11-13 occurring in unit 4 belong to the upper *griestoniensis* to *crenulata* Biozone of the middle Telychian. The graptolite levels in the uppermost part of unit 9 belong to the *insectus* to lower *centrifugus* Biozone of the upper Telychian.

6.3.6. General discussion on graptolite and chitinozoan biostratigraphy and chronostratigraphy and implications

The results of the graptolites confirm the results of the chitinozoans and refine them on some places. Below are the results of a combined chitinozoan and graptolite bio- and chronostratigraphy. A normal polarity is expected for the whole section when looking at the chitinozoans and the graptolites.

	Unit	Graptolite level / sample number	*Monograptus* ex gr. *priodon*	*Streptograptus exiguus*	*Stimulograptus* spp.	*Monograptus* spp.	*Retiolites angustidens*	*Monoclimacis geinitzii*	*Monograptus priodon*	*Torquigraptus* spp.	*Monoclimacis* spp.	*Cochlograptus veles*	*Torquigraptus australis*	*Retiolites geinitzianus*	*Giganteograptus* spp.	*Pristiograptus praedubius*	*Monograptus pseudocultellus*	*Cyrtograptus* spp.	*Mediograptus morleyae*	*Monoclimacis linnarssoni*	*Monoclimacis vomerina*	*Monoclimacis basilica*	*Pristiograptus* spp.	*Mediograptus morleyae*	*Retiolites* spp.	*Pristiograptus largus*	*Monoclimacis kettneri*	*Monograptus firmus*	*Mediograptus* spp.	nautiloid fragment	Graptolite biozonation
Path	9	JM 11-02	X																				X	X							*insectus*-lower *centrifugus*
		JM 11-01							cf.																						
		JM 12-23																	?												
		JM 11-04	X								X																		X	X	
		JM 11-18																	X							aff.	X	aff.			
		M																			cf.										
		L				X					X									cf.					X						
		K																				?									
		J							X		X			X					X				X	X							
		H																				aff.									
		F							X					X	X	X	X	X	X	cf.	X	?									
	4	JM 11-12 + JM 11-13					?		?	X		X	X																		upper *griestoniensis-crenulata*
		G									X																				
		E					?	cf.	?		X	X	X																		
		D						cf.	X	X																					
		C					X	cf.																							
Brooklet	3	JM 12-15				X																									upper *turriculatus-crispus*
		JM 12-14	X	X	?																										
		B	X	X																											
		A	X																												

Table. II.6.3. Graptolite results of Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville.

The distinction between unit 1 and unit 2 is made because of the separation of them in the outcrop (approximately 11.3 meters from the southern end of unit 1 to the northern end of unit 2). The only difference between them is the grain size that is a lot finer in unit 2. Probably unit 1 and unit 2 can be connected with each other and there is fining upwards trend towards unit 2. Hence we assume that unit 2 is not that much younger in comparison with unit 1 if faults are not present between these two outcrops. Unit 1 ranges from the upper part of the middle Aeronian to the lower part of the upper Aeronian. Unit 3 can be placed in the lower Telychian. Hence unit 2 has an age of lower part of the upper Aeronian to lowermost Telychian.

The graptolites in unit 3 indicate the upper *turriculatus* to *crispus* Biozone of the lower Telychian. This supports the chitinozoan data placing the unit in the lower Telychian based on the occurrence of *Eisenackitina dolioliformis* and *Conochitina malleus*.

The graptolites in unit 4 indicate the presence of the upper *griestoniensis* to *crenulata* Biozone of the middle Telychian refining the age assignment of the chitinozoans (see above). It means that sediment is missing from the lower *griestoniensis* Biozone because we know that deposition took place at that time interval (see chapter II.5, section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville). Hence a fault is present between unit 3 and unit 4 to explain this.

Unit 5 ranges from the middle of the *Eisenackitina dolioliformis* Biozone (lower to middle Telychian) into the *Angochitina longicollis* Biozone (middle Telychian). The *Angochitina longicollis* Biozone of Nestor (2012) can be correlated, according to the same author, with the lower part of the *Oktavites spiralis* Biozone. In unit 7 *Belonechitina cavei* occurs limiting the upper age of unit 5 to the middle Telychian (see below).

Unit 7 is placed in the middle Telychian but is younger than unit 5. The presence of *Belonechitina cavei* indicates that we are still in the *Angochitina longicollis* Biozone of Nestor (2012). The species occurs until the middle part of the *Angochitina longicollis* Biozone (Nestor, 2012). Mullins & Loydell (2001) has found that this species has his highest occurrence in the lower part of the *spiralis* Biozone. Unit 6 has an age that is placed between unit 5 and unit 7, hence middle Telychian.

Not so much information is present about unit 8. No fossils (no chitinozoans and no graptolites) are found. The lithology resembles to the underlying units 3, 4, 5, 6, and 7. The unit occurs between unit 7 and unit 9. Hence an age of middle Telychian is expected and can be correlated in the *Oktavites spiralis* Biozone although the *Cyrtograptus lapworthi* Biozone cannot be excluded.

The graptolites of the uppermost part of unit 9 belong to the *insectus* to lower *centrifugus* Biozone of the upper Telychian to the Llandovery/Wenlock boundary.
In one sample of unit 9, JM 09-135, *Conochitina acuminata* is present indicating a range of the *Cyrtograptus lapworthi* Biozone up to the Llandovery/Wenlock boundary (Nestor, 2012). This sample is located approximately 4.3 meters lower than the outcrop where graptolites

occur of the *insectus* to lower *centrifugus* Biozone. Hence unit 9 can be placed in the *lapworthi* Biozone up to the lower *centrifugus* Biozone.

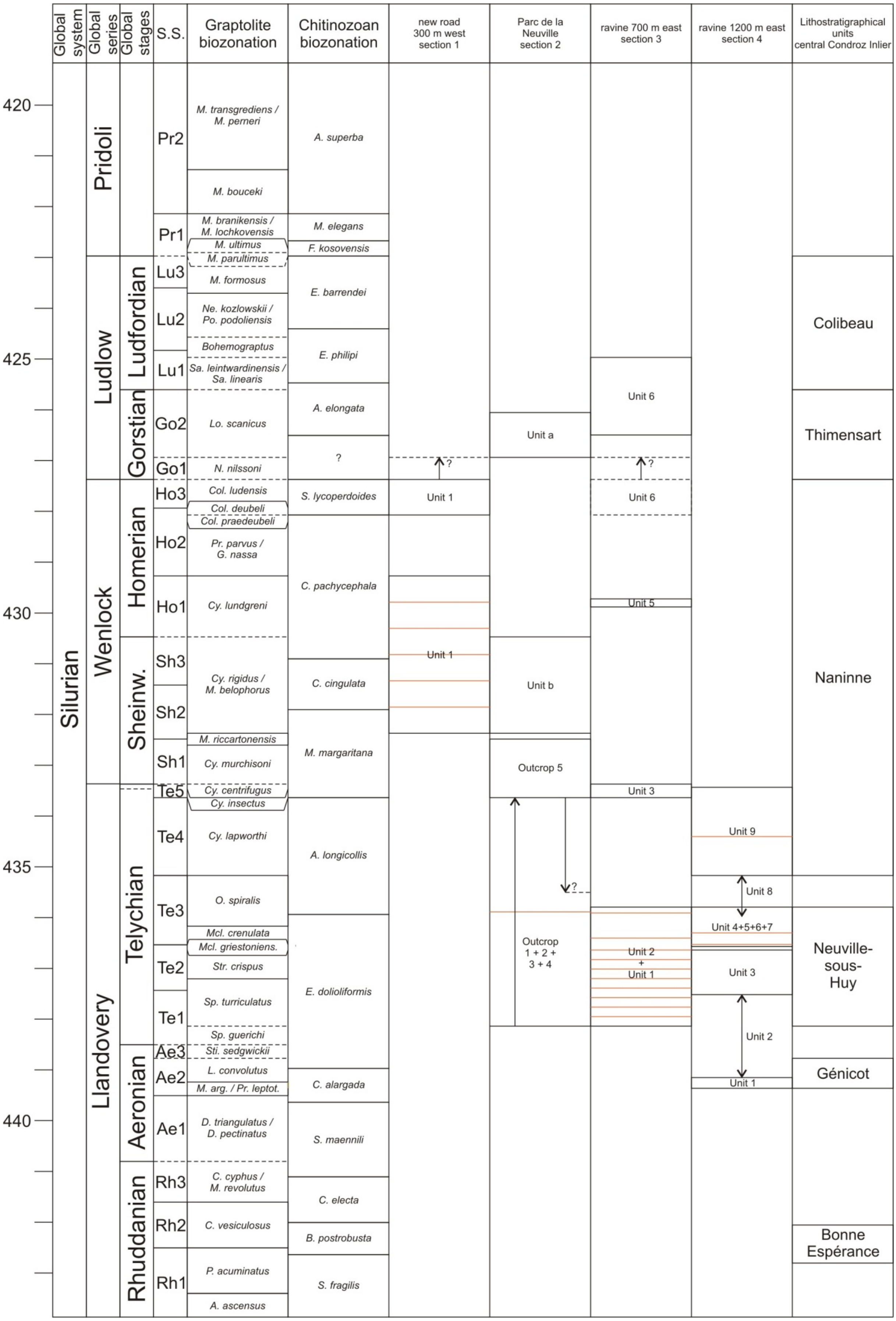
A fault zone is observed between unit 8 and unit 9. This is supported by the bio- and chronostratigraphically data. Hence a fault is present between unit 8 and unit 9.

6.3.7. Correlation of the Llandovery in section Neuville-sous-Huy, Parc de la Neuville, section ravine 700 m east of Parc de la Neuville, section ravine 1200 m east of Parc de la Neuville

A correlation of the Llandovery sediments of the three sections of Neuville-sous-Huy described in the chapters 3, 5 and 6 is not so easy. An overview of all the units of the four sections of Neuville-sous-Huy being placed in the chronostratigraphy can be found in fig. II.6.7. The sections have been numbered from west to east as followed: new road 300 m west of Parc de la Neuville (section 1, not containing sediments of the Llandovery), Parc de la Neuville (section 2), ravine 700 m east of Parc de la Neuville (section 3), ravine 1200 m east of Parc de la Neuville (section 4). The sections contain sediments that are in most cases different from other section. The observed hiatuses are most probably formed due to the lack of exposure of the sediments and the presence of faults.
The volcaniclastic layers present in the sections have not been used to correlate the units. These layers can change laterally on short distances and hence cannot be used as a correlation tool.

The oldest units present in the sections are unit 1 and unit 2 of section 4. Unit 1 can be placed in the upper part of the middle Aeronian to the lower part of the upper Aeronian. We assume that unit 2 is closely related to unit 1 and is not younger than the *turriculatus* Biozone (lower Telychian).

The basal sediments of unit 1 of section 3 belong to strata of the *turriculatus-crispus* Biozone. The strata of unit 1 of the same section are quite undisturbed and contain almost no faults. Unit 3 of section 4 can be correlated with unit 1 of section 3; unit 4 of section 4 can be correlated with the upper part of unit 1 of section 3.



Global system
Global series
Global stages
S.S.
Graptolite biozonation
Chitinozoan biozonation
new road 300 m west section 1
Parc de la Neuville section 2
ravine 700 m east section 3
ravine 1200 m east section 4
Lithostratigraphical units central Condroz Inlier
420
425
430
435
440
Silurian
Pridoli
Ludlow
Wenlock
Llandovery
Ludfordian
Gorstian
Homerian
Sheinw.
Telychian
Aeronian
Rhuddanian
Pr2
Pr1
Lu3
Lu2
Lu1
Go2
Go1
Ho3
Ho2
Ho1
Sh3
Sh2
Sh1
Te5
Te4
Te3
Te2
Te1
Ae3
Ae2
Ae1
Rh3
Rh2
Rh1
M. transgrediens / M. perneri
M. bouceki
M. branikensis / M. lochkovensis
M. ultimus
M. parultimus
M. formosus
Ne. kozlowskii / Po. podoliensis
Bohemograptus
Sa. leintwardinensis / Sa. linearis
Lo. scanicus
N. nilssoni
Col. ludensis
Col. deubeli
Col. praedeubeli
Pr. parvus / G. nassa
Cy. lundgreni
Cy. rigidus / M. belophorus
M. riccartonensis
Cy. murchisoni
Cy. centrifugus
Cy. insectus
Cy. lapworthi
O. spiralis
Mcl. crenulata
Mcl. griestoniens.
Str. crispus
Sp. turriculatus
Sp. guerichi
Sti. sedgwickii
L. convolutus
M. arg. / Pr. leptot.
D. triangulatus / D. pectinatus
C. cyphus / M. revolutus
C. vesiculosus
P. acuminatus
A. ascensus
A. superba
M. elegans
F. kosovensis
E. barrendei
E. philipi
A. elongata
?
S. lycoperdoides
C. pachycephala
C. cingulata
M. margaritana
A. longicollis
E. dolioliformis
C. alargada
S. maennili
C. electa
B. postrobusta
S. fragilis
Unit 1
Unit 1
Unit a
Unit b
Outcrop 5
Outcrop 1 + 2 + 3 + 4
Unit 6
Unit 6
Unit 5
Unit 3
Unit 2 + Unit 1
Unit 9
Unit 8
Unit 4+5+6+7
Unit 3
Unit 2
Unit 1
Colibeau
Thimensart
Naninne
Neuville-sous-Huy
Génicot
Bonne Espérance

Fig. II.6.7. Previous page. The units present in the four sections of Neuville-sous-Huy (Parc de la Neuville, section ravine 700 m east of Parc de la Neuville, section ravine 1200 m east of Parc de la Neuville, section new road 300 m west of Parc de la Neuville) and placed in the chronostratigraphy. The volcaniclastic layers present in the sections are indicated by an orange line. On the right the lithostratigraphy of the central Condroz Inlier as result by our study is given. Chronostratigraphy, numerical ages and graptolite biozonation are from Gradstein *et al.* (2012); the stage slices are from Cramer *et al.* (2011), the Silurian global chitinozoan biozonation is from Verniers *et al.* (1995).

Although faults are present in unit 4, 5, 6, 7 and 8 of section 4 an almost continuously sedimentary record is present of the upper *griestoniensis* Biozone up to a level that can be correlated with the lower part of the *Oktavites spiralis* Biozone (middle Telychian). The fault F1 present in section 3 just above the base of unit 2 has caused not so much “removal” of the sediments and lack of observation of the sedimentation record. Units 5, 6, 7, and 8 of section 4 are correlated with unit 2 of section 3. Finer parts in the mudstone is observed in unit 2 of section 3 together with coarser parts of the mudstone. These alternations in unit 2 of section 3 have been found in units 5, 6, 7, 8 of section 4. Units 5 and 7 of section 4 contain coarse mudstone; units 6 and 8 of section 4 contain fine mudstone. It is still possible that the units 5, 6, 7, 8 of section 4 do not reflect the exact same alternations present in unit 2 of section 3.
The sediments of outcrop 1, 2, 3 and 4 of section 2 do not contain chitinozoans to place these sediments accurately in the chronostratigraphy. The presence of *Eisenackitina causiata* indicate an early Telychian age up to the middle Sheinwoodian (see chapter II.3). We assume a lower to upper Telychian age for these sediments based on a different facies that is present certainly starting from the *Cyrtograptus insectus* Biozone (upper Telychian) present in section 3 and 4.

Starting from the *Cyrtograptus insectus* Biozone laminated hemipelagites occur. This lithology is almost continuously present in the upper Telychian to Wenlock sediments of Neuville-sous-Huy and the Condroz Inlier.

Chitinozoan plates

Plate II.6.1. Chitinozoans from Neuville-sous-Huy, section ravine 1200 m east of Parc de la Neuville.

1. *Conochitina iklaensis*?. L: >169 µm; Dp: 61 µm. JM 09-120. Unit 5.

2. *Belonechitina cavei*. L: ≥182 µm; Dp: 67 µm. JM 09-120. Unit 5.

3. *Belonechitina cavei*. L: >50 µm; Dp: 70 µm. JM 09-125. Unit 5.

4. *Bursachitina* aff. *conica*. L: >363 µm; Dp: >190 µm; Dc: 118 µm. JM 09-126. Unit 5.

5. *Bursachitina* aff. *conica*. L: 382 µm; Dp: >160 µm. JM 11-17. Unit 9.

6. *Angochitina longicollis*. L: 182 µm; Dp: 73 µm; Dc: 41 µm. JM 09-126. Unit 5.

7. *Angochitina longicollis*. L: 187 µm; Dp: 71 µm; Dc: 39 µm. JM 09-126. Unit 5.

8. *Angochitina longicollis*. L: 152 µm; Dp: 63 µm; Dc: 26 µm. JM 09-126. Unit 5.

9. *Angochitina longicollis*. L: 228 µm; Dp: 78 µm; Dc: 43 µm. JM 09-126. Unit 5.

10. *Angochitina longicollis*. L: >188 µm; Dp: 75 µm; Dc: ≤40 µm. JM 09-126. Unit 5.

11. *Angochitina longicollis*. L: 230 µm; Dp: 83 µm; Dc: 40 µm. JM 09-126. Unit 5.

12. *Angochitina longicollis*. L: 164 µm; Dp: 68 µm; Dc: 33 µm. JM 09-126. Unit 5.

13. *Angochitina longicollis*. L: 211 µm; Dp: 91 µm; Dc: 45 µm. JM 09-126. Unit 5.

14. *Ramochitina* aff. *angusta*. L: 164 µm; Dp: 68 µm; Dc: 31 µm. JM 09-126. Unit 5.

15. *Ramochitina* aff. *angusta*. L: 221 µm; Dp: 73 µm; Dc: 30 µm. JM 09-126. Unit 5.

16. *Ramochitina* aff. *angusta*. L: 196 µm; Dp: 68 µm; Dc: 40 µm. JM 09-126. Unit 5.

Plate II.6.1.

Plate II.6.2. Chitinozoans from Neuville-sous-Huy, section ravine 1200 m east of Parc de la Neuville.

1. *Ramochitina* sp. 1. L: >120 µm; Dp: 75 µm; Dc: 27 µm. JM 09-126. Unit 5.

2. *Ramochitina* sp. 1. L: 149 µm; Dp: 82 µm; Dc: 35 µm. JM 09-126. Unit 5.

3. *Ramochitina* sp. 1. L: 155 µm; Dp: 87 µm; Dc: 35 µm. JM 09-126. Unit 5.

4. *Eisenackitina* aff. *inanulifera*. L: 126 µm; Dp: 85 µm; Dc: 45 µm. JM 09-126. Unit 5.

5. *Ramochitina* sp. L: 213 µm; Dp: 92 µm; Dc: 40 µm. JM 09-126. Unit 5.

6. *Eisenackitina causiata*. L: 122 µm; Dp: 73 µm; Dc: 47 µm. JM 09-126. Unit 5.

7. *Eisenackitina causiata*. L: 140 µm; Dp: 91 µm; Dc: 61 µm. JM 09-126. Unit 5.

8. *Eisenackitina causiata*. L: 114 µm; Dp: 63 µm; Dc: 53 µm. JM 09-126. Unit 5.

9. *Eisenackitina causiata*. L: 83 µm; Dp: 66 µm. JM 11-17. Unit 9.

10. *Eisenackitina causiata*. L: 90 µm; Dp: 59 µm; Dc: 39 µm. JM 11-17. Unit 9.

11. *Eisenackitina causiata*. L: 125 µm; Dp: 93 µm. JM 10-42. Unit 5.

12. Chain of 3 specimens of *Calpichitina densa*. L_{total}: 203 µm. JM 09-126. Unit 5.

13. Chain of 2 specimens of *Calpichitina densa*. L_{total}: 128 µm. JM 09-129. Unit 5.

14. Chain of 2 specimens of *Calpichitina densa*. L_{total}: 95 µm (3D measurements). JM 11-17. Unit 9.

15. *Conochitina acuminata*. L: 147 µm; Dp: 62 µm; Dc: 39 µm. JM 09-135. Unit 9.

16. *Desmochitina* sp. L: 90 µm; Dp: 73 µm. JM 10-43. Unit 5.

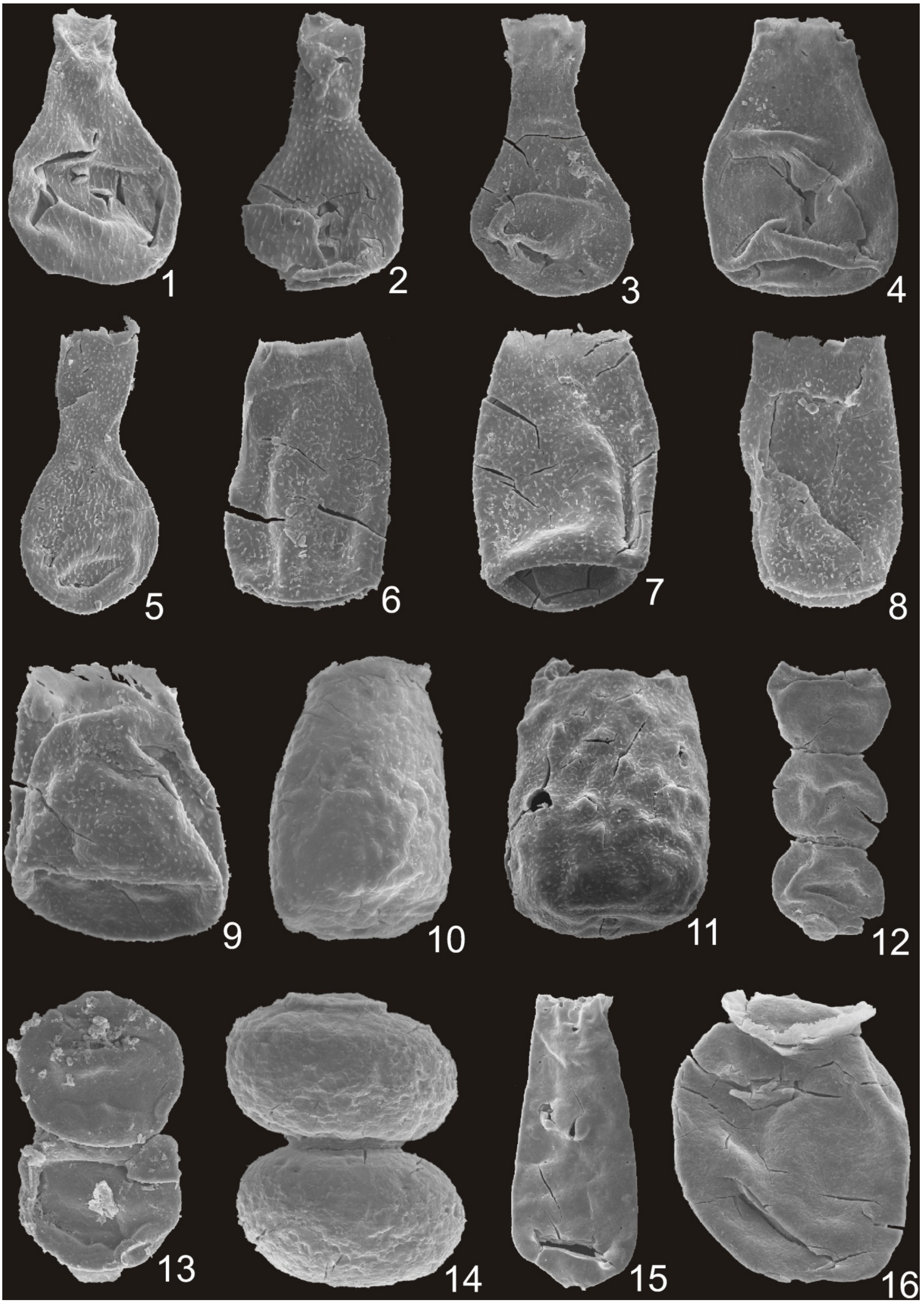


Plate II.6.2.

Plate II.6.3. Chitinozoans from Neuville-sous-Huy, section ravine 1200 m east of Parc de la Neuville.

1. *Bursachitina conica*. L: 295 µm; Dp: 174 µm; Dc: 101 µm. JM 11-11. Unit 4.

2. *Bursachitina conica*. L: 310 µm; Dp: 172 µm; Dc: 93 µm. JM 11-11. Unit 4.

3. *Conochitina* sp. L: 164 µm; Dp: 71 µm; Dc: 40 µm. JM 11-14. Unit 5.

4. *Ramochitina* sp. L: ≥163 µm; Dp: 67 µm; Dc: 23 µm. JM 11-17. Unit 9.

5. *Ramochitina* sp. L: ≥162 µm; Dp: 82 µm; Dc: 38 µm. JM 11-17. Unit 9.

6. *Ramochitina* sp. L: ≥144 µm; Dp: 90 µm. JM 11-17. Unit 9.

7. *Ramochitina* sp. L: ≥158 µm; Dp: 70 µm; Dc: 26 µm. JM 11-17. Unit 9.

8. *Ramochitina* sp. L: ≥135 µm; Dp: 76 µm; Dc: 28 µm. JM 11-17. Unit 9.

9. *Conochitina candoris*. L: 150 µm; Dp: 78 µm; Dc: 58 µm. JM 10-41. Unit 3.

10. *Conochitina candoris*. L: 125 µm; Dp: 65 µm; Dc: 44 µm. JM 10-41. Unit 3.

11. *Eisenackitina dolioliformis*. L: 192 µm; Dp: 108 µm. JM 10-41. Unit 3.

12. *Conochitina malleus*. L: 229 µm; Dp: 95 µm. JM 10-41. Unit 3.

13. *Conochitina iklaensis*. L: 239 µm; Dp: 53 µm. JM 10-41. Unit 3.

14. *Spinachitina* sp. L: 240 µm; Dp: 75 µm; Dc: 50 µm. JM 10-41. Unit 3.

15. *Cyathochitina caputoi*. L: 166 µm; Dp: 145 µm; Dc: 52 µm. JM 10-31. Unit 1.

16. *Belonechitina* aff. *postrobusta*. L: ≥200 µm; Dp: 84 µm; Dc: 70 µm. JM 10-31. Unit 1.

Plate II.6.3.

Plate II.6.4. Chitinozoans from Neuville-sous-Huy, section ravine 1200 m east of Parc de la Neuville.

1. *Spinachitina maennili*. L: 200 µm; Dp: 63 µm; Dc: 32 µm. JM 10-31. Unit 1.

2. Detail of plate 4, picture 1 showing the processes of *Spinachitina maennili*. JM 10-31. Unit 1.

3. *Spinachitina oulebsiri*. L: >125 µm; Dp: 58 µm; Dc: ≤35 µm. JM 10-33. Unit 1.

4. *Conochitina malleus*. L: >222 µm; Dp: 96 µm. JM 10-31. Unit 1.

5. *Conochitina malleus*. L: 220 µm; Dp: 82 µm; Dc: 62 µm. JM 10-31. Unit 1.

6. *Conochitina malleus*. L: ≥250 µm; Dp: 95 µm. JM 10-31. Unit 1.

7. *Conochitina malleus*. L: ≥133 µm; Dp: 68 µm. JM 10-32. Unit 1.

8. *Conochitina malleus*. L: ≥141 µm; Dp: 70 µm; Dc: 47 µm. JM 10-33. Unit 1.

9. *Conochitina alargada*. L: >220 µm; Dp: 70 µm. JM 10-31. Unit 1.

10. *Conochitina alargada*. L: >188 µm; Dp: 82 µm; Dc: <57 µm. JM 10-31. Unit 1.

11. *Conochitina iklaensis*. L: >192 µm; Dp: 58 µm. JM 10-31. Unit 1.

12. *Conochitina iklaensis*. L: >230 µm; Dp: 80 µm; Dc: <50 µm. JM 10-33. Unit 1.

13. *Cyathochitina kuckersiana*. L: ≥130 µm; Dp: 74 µm; Dc: 30 µm. JM 10-31. Unit 1.

14. *Cyathochitina campanulaeformis*. L: >167 µm; Dp: 97 µm; Dc: 40 µm. JM 10-33. Unit 1.

15. *Cyathochitina* sp. 1. L: ≥262 µm; Dp: 122 µm; Dc: 65 µm. JM 10-31. Unit 1.

16. *Cyathochitina* sp. 1. L: ≥235 µm; Dp: 111 µm; Dc: 49 µm. JM 10-33. Unit 1.

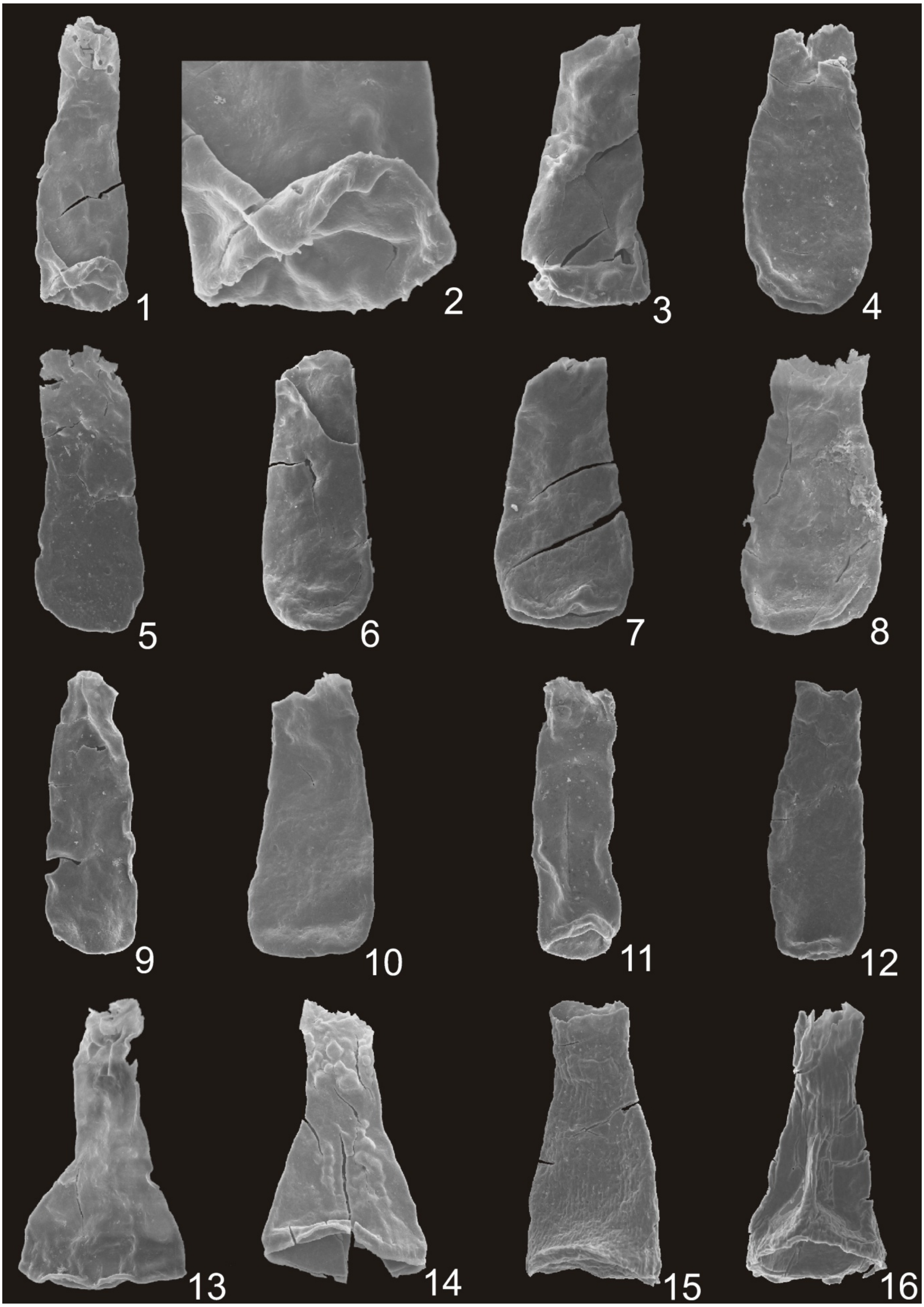


Plate II.6.4.

Graptolite plate

Plate II.6.5. Graptolites from Neuville-sous-Huy, section ravine 1200 m east of Parc de la Neuville.

A, L – *Monograptus priodon* (Bronn), limonitized specimens preserved in relief: A – (Sample F, No. P1903-F27), L – (Sample JM11-01). B, I – *Monoclimacis vomerina* (Nicholson), limonitized specimens preserved in relief: B – (Sample F, P1903-F8), I – (Sample F, No. 1903-F2). C1-C3, D, O, P1-P2 – *Mediograptus morleyae* Loydell & Cave, limonitized specimens in relief with partly preserved periderm, partly flaked off: C1-C3, group of three rhabdosomes and P1-P2, group of two rhabdosomes – (Sample F, No. P1903-F2); D – (Sample F, P1903-F31), O – (Sample JM11-02). E – *Monograptus pseudocultellus* Bouček , limonitized specimen in relief, partly flaked off, (Sample F, No. P1903-F34). F – *Monoclimacis kettneri* (Bouček), external mould of limonitized specimen preserved in relief, (Sample L, No. P1903-L2). G – *Cyrtograptus* sp., cf. *insectus* Bouček, proximal fragment of flattened specimen, (Sample F, No. 1902-F5). H – *Mediograptus kodymi* (Bouček), external mould of limonitized specimen preserved in low relief, (Sample J, No. 1904-J4). J, K – *Streptograptus exiguus* (Lapworth), flattened specimens: J – (Sample B, No. P1903-B16), K – (Sample B, No. P1903-B15), M – *Barrandeograptus pulchellus* (Tullberg), external mould with remains of periderm preserved in relief, (Sample F, No. P1903-F2). N – *Monoclimacis* sp., cf. *geinitzi* (Bouček), flattened, partly pyritized rhabdosome, (Sample D, No. P1903-D11). Q – *Torquigraptus australis* Štorch , incomplete flattened rhabdosome, (Sample E, No. P1903-E2). R – *Retiolites angustidens* Elles & Wood, partly limonitized rhabdosome, (Sample C, No. P1903-C7). All specimens x 6.

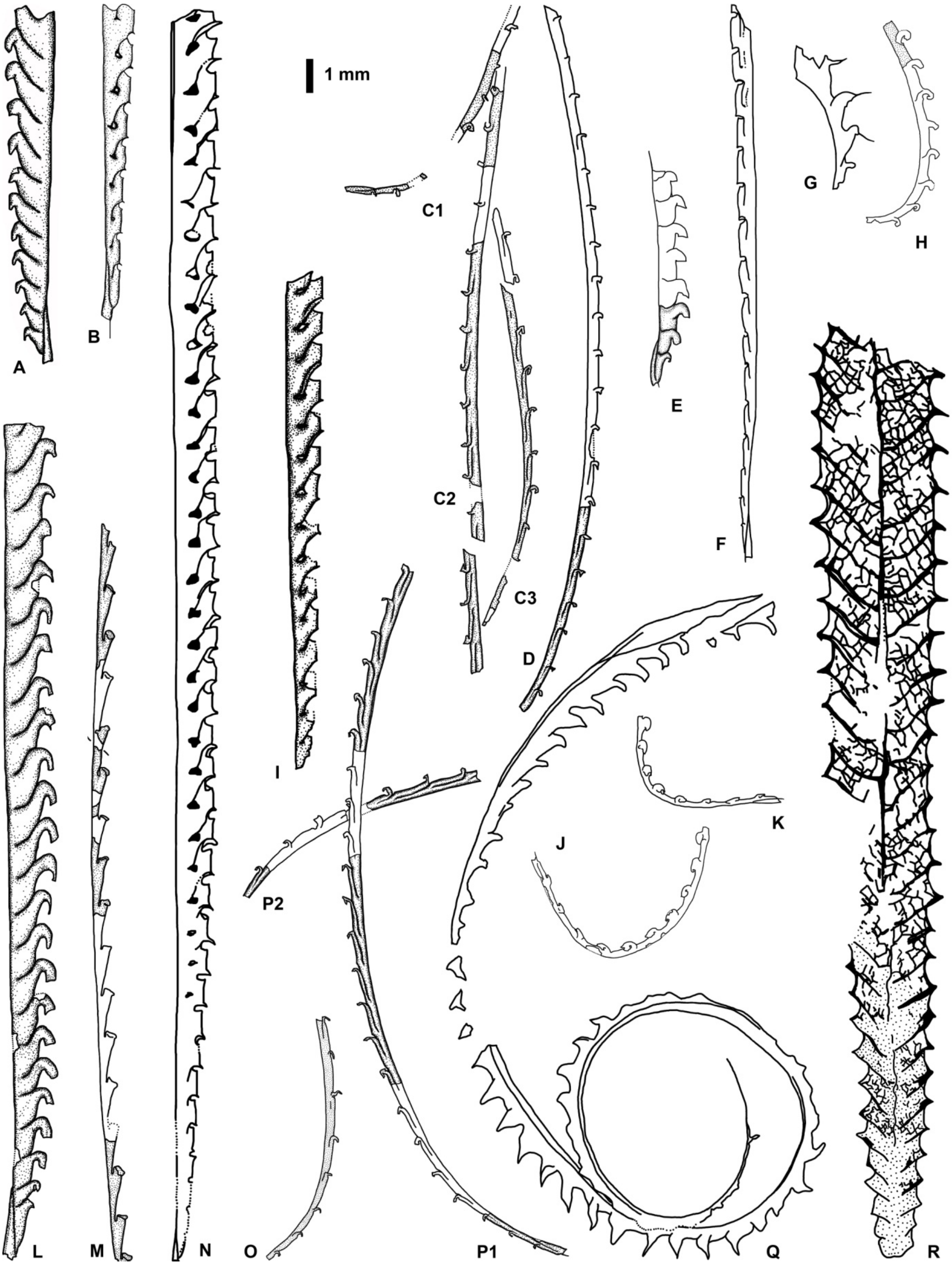


Plate II.6.5.

7. The volcaniclastic rocks of Neuville-sous-Huy

7.1. Earlier studies

Dumont (1848) is the first author to mention volcanic rocks in the Neuville-sous-Huy area. He describes traces of a quartzitic eurite between Neuville-sous-Huy and Ombret. An eurite is a felsite and is fine grained with in most cases devoid of any phenocrysts and mainly composed of quartz and feldspar. Malaise (1873 & 1874a, b) retake this mention without adding new information. Forir (1897) describes the rocks during an excursion: he observes porphyroids in the Parc de la Neuville and the ravine 1200 m east of Parc de la Neuville and eurites in the ravine 700 m east of the Parc de la Neuville.

De la Vallée Poussin (1898) describes an arkose in the Parc de la Neuville near a house and near the first pond and a porphyre in the ravine 700 m east. The porphyre is formed by a cryptocrystalline matrix with small and larger crystals of quartz and feldspar. The feldspar is partly made up by plagioclase and maybe partly of orthoclase. He describes the crystals as formless and mentions the presence of mica. He suggests that this rock is a tuff. In the Parc de la Neuville along the first pond he describes that the outcrop starts with a consolidated conglomerate with cores of shale and grains of quartz and kaolinizated feldspar. It is succeeded by finer grained rocks with better preserved feldspar and followed by a greenish arkose with a fine grain. Below the microscope he finds that the feldspar is sometimes very abundant and belongs to orthoclase or plagioclase. It is sometimes weathered, sometimes fresh, sometimes broken. The cement is brownish to greenish, in most cases isotrope and sometimes chlorite bearing. There is also a presence of rock fragments.

Some of the descriptions of Michot (1934) has already been described in the previous chapters 3, 5 and 6. In the ravine 700 m east of Parc de la Neuville he identified four keratophyre levels and one arkose. He groups level b and level d, petrographically these are identical, with the following description. There are phenocrysts present of albite (generally without anorthite or rarely up to 10 %) with a maximum diameter of 1-2 mm. They are present in a microfelsite matrix of flattened albite of an average length between 1 and 2 mm. The albite of the matrix is rarely accompanied with quartz. Accessory some calcite and dolomite is present. He named these two levels a keratophyre. Level h and j are also grouped together. Phenocrysts of both fractured feldspar and quartz are present, in the order of 2 mm large. They are embedded in a microfelsite matrix of flattened albite without any anorthite with some quartz. These two levels are labeled as a quartz keratophyre.

The arkose present in the Parc de la Neuville, the ravines 700 m east and 1200 m east of Parc de la Neuville is mainly made up of feldspar (approximately 75 % of the large grains) slightly rounded and in most cases angular quartz. The feldspars are mainly made up of albite and accessorily plagioclase containing a maximum of 10 % anorthite. Locally flakes of chlorite are present containing zircon. These flakes are the result of weathering of black mica. The arkose of the ravine 700 m east of Parc de la Neuville is finer grained in comparison with the other two sections.

Michot (1938) adds with a further description of the volcaniclastic rocks focussing on the arkose. The arkose is in the basal part very coarse and the grains have an average diameter of 2-3 mm. Higher up it becomes finer, the massive character disappears and the rock becomes more shaly. The coarsest layers are characterized by the juxtaposition of coarse, angular grains of quartz and feldspar with a matrix of very fine material of sericite-chlorite. The feldspar is 3-4 times more abundant than the quartz. Only in the coarsest part the grains are very lightly rounded. In the matrix lines do occur that are bended, concave and convex. They are interpreted as devitrified glass. Some small debris of eruptive rock is also present. Flakes consisting of cryptocrystalline chlorite are present. Some of them still do contain some brownish biotite. Others contain small crystals of apatite and zircon. Hence the arkose is formed by coarse material derived from the disintegration of an eruptive rock that is porphyric and microlithic. The fine material came originally from volcanic ashes. When the rock becomes finer higher up the matrix of sericite-chlorite becomes more and more important and the grains of quartz and feldspar become isolated. Some of this material is made up of very fine volcanic ashes. These ashes are devitrified and are made up of very fine quartz. On other places they are transformed to calcite. The association of coarse material at one hand and fine material at the other hand is explained as originating from a volcanic apparatus. The angular nature of the grains indicate that the grains have weakly been transported and hence the volcanic apparatus would have been nearby.

Corin (1965) described the calcareous rock that is present in the northern part of the ravine 700 m east of Parc de la Neuville without indicating which level. It is very fine grained and formed by an accumulation of glass fragments, generally silicified, and small crystals of feldspar in a greenish, isotropic matrix and rounded, scattered grains of carbonate. It is a fine tuff. Further southwards of the ravine 700 m east of Parc de la Neuville near the confluence of two brooklets a second eurite outcrops. It corresponds most probably to level j of Michot (1934). The porphyroids, corresponding to the arkose, are coarse, medium or fine grained in the Parc de la Neuville, the ravine 700 m and the ravine 1200 m east of Parc de la Neuville. They have the properties of lavas or tuffs.

Vandevelde (1976) discovered four more levels in the ravine 700 m east in comparison with Michot (1934) giving a total of nine volcaniclastic layers. The description of these layers is found in table II.7.1. The correlation of the volcaniclastic layers with these of Michot is given in fig. II.5.2.

Volcaniclastic layer	Unit	Description
V9	6	Light grey-green, compact with an aphanitic structure dipping 60° south.
V8	5	Light grey green with an aphanitic structure. The contact with the underlying and covering shales is not visible. The thickness is 4 to 5 meters.
V7	5	At the base it looks like a coarse-grained sandstone passing upwards into a compact grey-green rock with an aphanatic structure. At the

		top it looks like a fine-grained sandstone. The thickness is approximately 1.5 meters
V6	3	Green grey, clearly bedded in beds with a thickness of a few centimeters up to 20 cm. The rock looks like a fine-grained, rather well sorted sandstone with an internal stratification more clearly visible in the thinner beds. Sporadically small feldspath grains and fyllitic minerals occur. The thickness is approximately 2.3 meters.
V5	3	Green-grey, in appearance a coarse-grained, poorly sorted sandstone. It has scattered phenocrysts of feldspath, small rounded lithic fragments and dark green phillitic minerals (chlorite?) orientated parallel to the bedding. The rock becomes finer grained and more shaly upwards due to a larger amount of clayey material. The rock has clearly a clastic appearance. The thickness is approximately 2.4 meters.
V4	3	Strongly weathered.
V3	2	Fine-grained and weakly stratified; quite strongly weathered and locally reddish coloured. The thickness is 0.80 meters.
V2	2	Grey to brown-grey, compact and fine-grained. At the base scattered phenocrysts do occur up to 2 mm in size. The structure becomes more clastic higher up. The thickness is 1.7 meters.
V1	2	Grey-green, fine-grained with rare phenocrysts of feldspath and a clear clastic structure but without stratification.

Table II.7.1. The volcaniclastic layers present in the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville as described by Vandevelde (1976).

Maes (1976) described one more volcaniclastic level (V1) in comparison with Michot (1934), giving a total of three volcaniclastic layers. A description of the volcaniclastic layers is found in table II.7.2.

Volcaniclastic layer	Unit	Description
“Arkose”	5	Coarse-grained with a cement of chlorite. Clear banks do occur with a thickness of approximately 10 cm.
V2	5	Grey blue volcanic rock with the aspect of a sandstone. It is 50 cm thick and it is dipping 56° to the south.
V1	1	Tuff with a minimal thickness of 40 cm

Table II.7.2. The volcaniclastic layers present in the section Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville as described by Maes (1976).

7.2. New data

We will discuss the “arkose” as defined by Michot (1934) and some of the “keratophyre” levels separately.

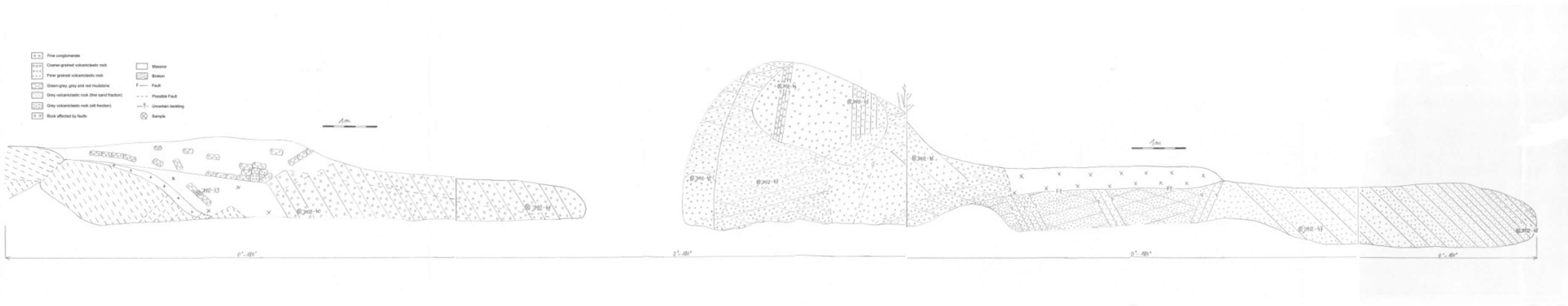
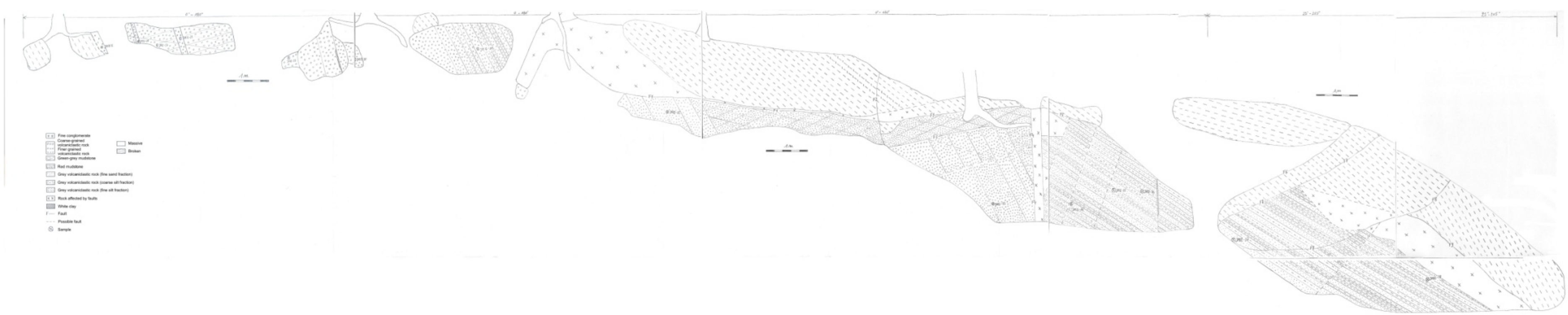


Fig. II.7.1. Above. Section along the mamelon 105. Below. Section in the abandoned quarry.



7.2.1. "Arkose"

The "arkose" is present in the three sections of Neuville-sous-Huy: northern part of Parc de la Neuville, ravine 700 m east of Parc de la Neuville, ravine 1200 m east of Parc de la Neuville. They share the same petrographical characteristics hence we discuss them together. The stratigraphical position of the "arkose" will be discussed in chapter 7.2.1.6.

7.2.1.1. Parc de la Neuville

Fig. II.7.2. Outcrop of the elliptic zone with an unclear bedding of the rock. The two directions (northerly and southerly direction) are indicated on the photo.

In the Parc de la Neuville the “arkose” is present twice: along a small path west of mamelon 105 (outcrop 2) and in an abandoned quarry situated between the first and the second pond (outcrop 4). See also fig. II.3.2 and fig. II.7.1. A description of the outcrop has been made below.

Along a small path just west of mamelon 105 (see fig. II.7.1.), indicated by outcrop 2) the contact of the volcaniclastic layer with the mudstone is quite abrupt. It is not parallel with the underlying mudstones and is probably a fault contact. At the base of the volcaniclastic rock a thin bed (maximum 25 cm thick) of fine conglomerate is present. It is followed by a zone that is very poorly outcropping, possible caused by the presence of faults. At the bottom of the outcrop grey mudstone occur. Further southwards the outcrop becomes more clear, possibly caused by the decrease of faults (but they are still present). Here it is possible to make a measurement of the bedding: Strike 105/Dip 59S. The outcrop is made up by coarse volcaniclastic rock consisting of angular grains of approximately 2 mm large. These grains consist of quartz, plagioclase and green fine grained fragments. A matrix is almost not observable. It is followed by an observational hiatus in the outcrop of approximately 2.5 m thick. Northwards of this hiatus the volcaniclastic rock has a thickness of approximately 6 meters.

After the hiatus in the outcrop volcaniclastic rock is outcropping over a horizontal distance of 16 meters. It starts with an outcrop reaching a height of approximately 3 meters above the path. A big elliptic zone is present here at the upper part of the outcrop with as long axis approximately 1.5 meters (see fig. II.7.2). But there is no lithological difference with the rocks just outside of this elliptic zone. The volcaniclastic rock consists of angular grains and green fragments of approximately 1 mm in diameter. It is lightly calcareous. The bedding of the volcaniclastic rock is here not clear. Some parts give a northern dip (measurements of Strike 255/Dip 80N, Strike 253/Dip 70N, Strike 252/Dip 60N), other parts give a southern dip (Strike 098/Dip 42S, Strike 100/Dip 46S) as can also be seen in fig. II.7.1. Which dip is displaying the bedding of the rock is not clear. The same what the other dip is displaying. Further southwards a sub horizontal fault F1 does occur (see fig. II.7.1). Above this fault just southwards of the elliptic zone the rock has the same lithology as from the elliptic zone. But southwards still above the fault F1 a light grey, fine grained weathered rock occurs almost not outcropping. No crystals can be seen. Below the fault the rock is dark grey and coarser grained with crystals of approximately 1 mm in diameter. Northern and southern dips do also occur. Further southwards a clear southern bedding has been observed together with a finer grain size and the rock becomes more bedded. This rock is still volcaniclastic in origin. The stratigraphical thickness of the volcaniclastic layer is at least 19.1 meters.
At the southern end of mamelon 105 a small outcrop exists with a total length of 3 meters (see fig. II.3.2). It consists of quite coarse volcaniclastic rock. The grain size is comparable with the volcaniclastic rock that is present just southwards of the elliptic zone and consists of angular grains and green fragments. The beds are dipping to the south.

Fig. II.7.3. The oblique contact of the mudstones (on the left) with the volcaniclastic layer (on the right) in the abandoned quarry.

In the abandoned quarry (see fig. II.7.1.), indicated by outcrop 4, in the most northern part, the volcaniclastic layer is in contact with the mudstones further northwards (see fig. II.7.3). The contact is parallel with the mudstones high in the outcrop. But downwards in the outcrop the contact is oblique. It can be interpreted that the volcaniclastic layer has cut in the mudstones 12 cm deep or it is a fault contact. The volcaniclastic layer belongs to the very coarse sand fraction up to a fine conglomerate. It is made up of colourless, white and dark crystals (often brownish weathered) of 2-3 mm big that are angular but sometimes a bit rounded. It is slightly calcareous. The volcaniclastic layer is here 15 cm thick up to the end of the outcrop.

The outcrop is followed by an observational hiatus of approximately 40 cm thick. After the hiatus coarse grained volcaniclastic rock occurs of 2.6 meters thick. It is a little bit finer but still clearly coarse-grained. The rocks are quite crumbled except for two beds that are more massive and less weathered (6.5 and 15 cm thick). They show no lithological difference with the neighboring rocks. The beds are dipping to the south (Strike 106/Dip 64S).

Fig. II.7.4. The ellipsoidal, green, fine-grained fragment completely surrounded by volcaniclastic rock.

After a hiatus of approximately 1.30 meters volcaniclastic rock crops out in southdipping massive banks 2.2 meters thick. It is still coarse-grained with grains of 1-2 mm (the same as previous one), little green fragments and little matrix. An ellipsoidal, green, fine-grained fragment (longest axis is 11 cm) is present completely surrounded by volcaniclastic rock (see Fig. II.7.4). It looks the same as the little green fragments that are present in the volcaniclastic rock. It is followed by an observational hiatus of approximately 1.4 meters thick and southwards 2.4 meters volcaniclastic rock appears dipping to the south (Strike 109/Dip 62S). Individual grains can still be seen by the naked eye. At the uppermost part of the outcrop a subhorizontal, gently south dipping fault occurs with above this fault the presence of green to olive green mudstone.

Southwards of this outcrop an approximately 3 meters thick, possibly fine-grained rock occurs clearly affected by faults (a fault zone). The exact nature of the rocks cannot be determined. It is a fault zone that is connected southwards to fault F1. Above the fault F1 green to olive green, south dipping mudstone do occur. Also red mudstone is present. Below the fault F1 volcaniclastic rock occur dipping southwards. It is finer grained (fine sand fraction) and the matrix dominates over the crystals. Southwards of the vertical fault F2 finer volcaniclastic rock does occur with rusty patches dipping to the south. Below fault F1 a subhorizontal fault F3 does occur. Below fault F3 volcaniclastic rock does occur that is slightly coarser in comparison with these occurring just northwards. The total thickness of the volcaniclastic rock starting from the fault zone up to the vertical fault F4 is approximately 9 meters.

Southwards of the vertical fault F4 green-grey volcaniclastic rock occur belonging to the fine sand to silt fraction. It is bedded and ritmic with banks that are massive and coarser grained, and parts that are more shaly and finer grained. Individual crystals cannot be seen but orange patches do occur. The beds are dipping to the south (Strike 105/Dip 35S). The thickness is 2.4 meters. At the upper part of the outcrop (divided by fault F5) green to olive green mudstone occur.

After an observational hiatus of approximately 60 cm the same lithology appears as in the previous part although generally finer. Faults disturbing the rocks are unfortunately present. The bedding is to the south. A south dipping fault F9 is present. Below fault F9 south dipping volcaniclastic rock occurs, above fault F9 south dipping green to olive green mudstone occurs. Towards the south volcaniclastic layer disappears followed by fault F9 and southwards green to olive green mudstone.

The total thickness of the volcaniclastic layer in the excavation is approximately 22 meters thick. A weakly south dipping fault is present in almost the whole excavation with below the volcaniclastic layer and above green to olive green mudstone with occasionally a bed of red mudstone. The volcaniclastic layer becomes finer going southwards (from a fine conglomerate up to the clay fraction) indicating a general normal polarity for the abandoned quarry.

7.2.1.2. Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville

The volcaniclastic layer V6 (see fig. II.7.5), as defined by Vandevelde (1976), corresponds to the “arkose” of Michot (1932a, 1934). It consists of green-grey, stratified volcaniclastic rock with cross-bedding present at the base. At the base it is quite coarse, with millimetric crystals (a.o. green), going finer upwards. It is exposed in centimetric banks. Weathering is always present. It passes gradually upwards into green-grey mudstone. Volcaniclastic layer V6 is 208 cm thick.

7.2.1.3. Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville

A different numbering have been chosen by us for the volcaniclastic rocks occurring in the section of Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville to avoid confusing with the other sections. The “arkose” of Michot (1932a & 1934) corresponds to level Vγ and is present along the pathway (see fig. II.6.3 and II.7.6). It was described as an “arkose” by Michot (1932a & 1934), Maes (1976) and Maes *et al.* (1978). At the base the grain size is coarse to very coarse grained with grains up to 2 mm in size. The rock is in most cases weathered with white, brown, green and colourless crystals. The grain size decreases upwards but at the top the mean grain size is still in the sand fraction. The volcaniclastic layer has a total thickness of 308 cm. The base is erosive (see fig. II.7.6) into the underlying mudstone cutting down up to 40 cm deep which indicates a normal polarity.

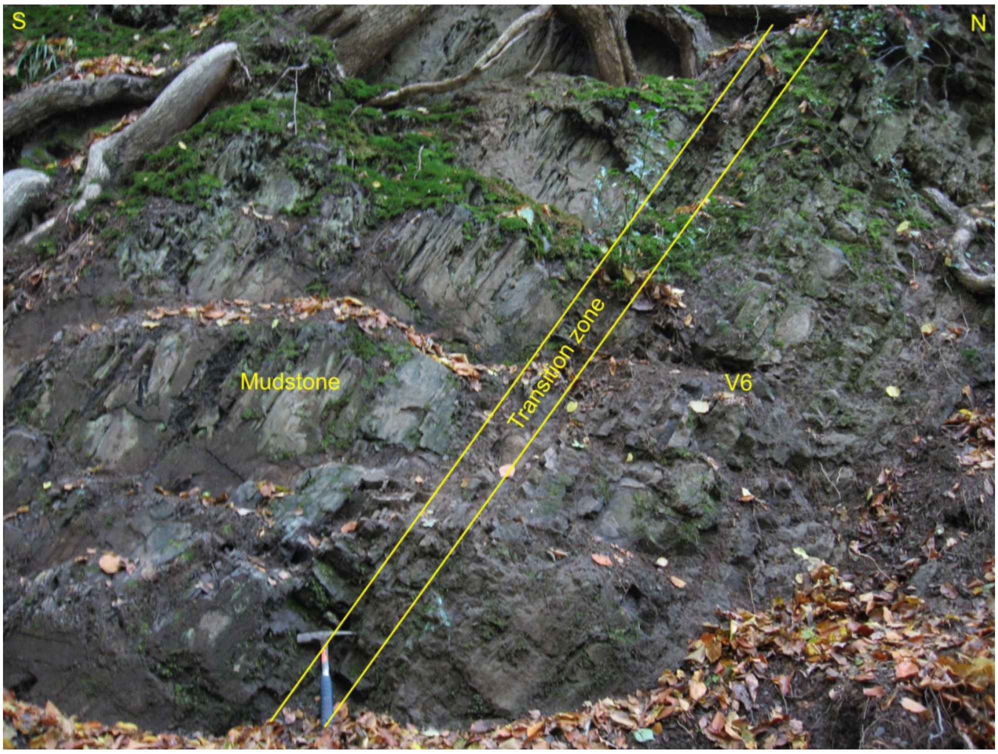


Fig. II.7.5. The stratified volcaniclastic layer V6. The base of V6 is just out of the picture (on the right).

Fig. II.7.6. Outcrop of the base of Vγ.

It is followed upwards by a softer bed with still hard parts in it. The rock (the hard parts) is grey, most of the time weathered to yellowish colours, and very fine-grained. Further upwards the weathering is more and more pronounced with at the top completely weathered, brown yellowish to white clay. In the basal part, approximately 25 cm thick, there is still rock present. Further upwards the clayey component becomes more and more prominent until in the uppermost 13 cm only a clay is present. The softer bed has an estimated thickness of 50 cm. The top is not completely parallel with the bedding of the covering mudstones. Possibly a fault is present, causing the presence of the clay.

7.2.1.4. Petrographical study of the "arkose"

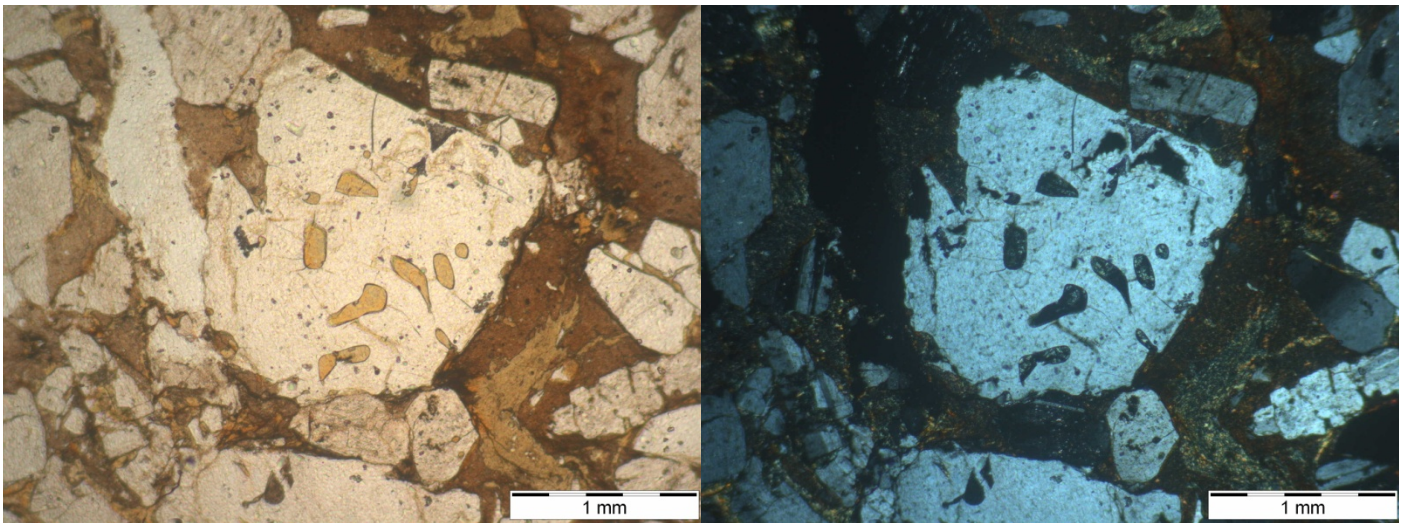


Fig. II.7.7. A quartz crystal containing inclusions, possibly devitrified glass. Sample JM 12-41 along the mamelon 105. The image on the left is taken in plane-polarized light; the image on the right is taken with crossed polars.

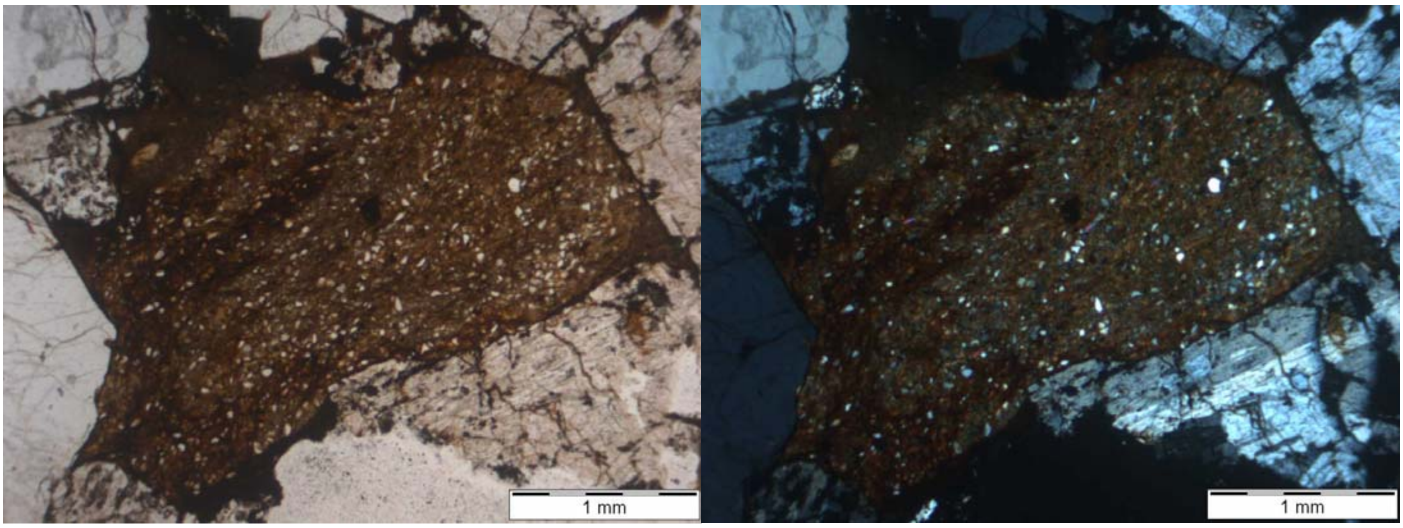


Fig. II.7.8. A sedimentary rock fragment. Sample JM 12-25 at the base of the volcaniclastic layer in the abandoned quarry. The image on the left is taken in plane-polarized light; the image on the right is taken with crossed polars.

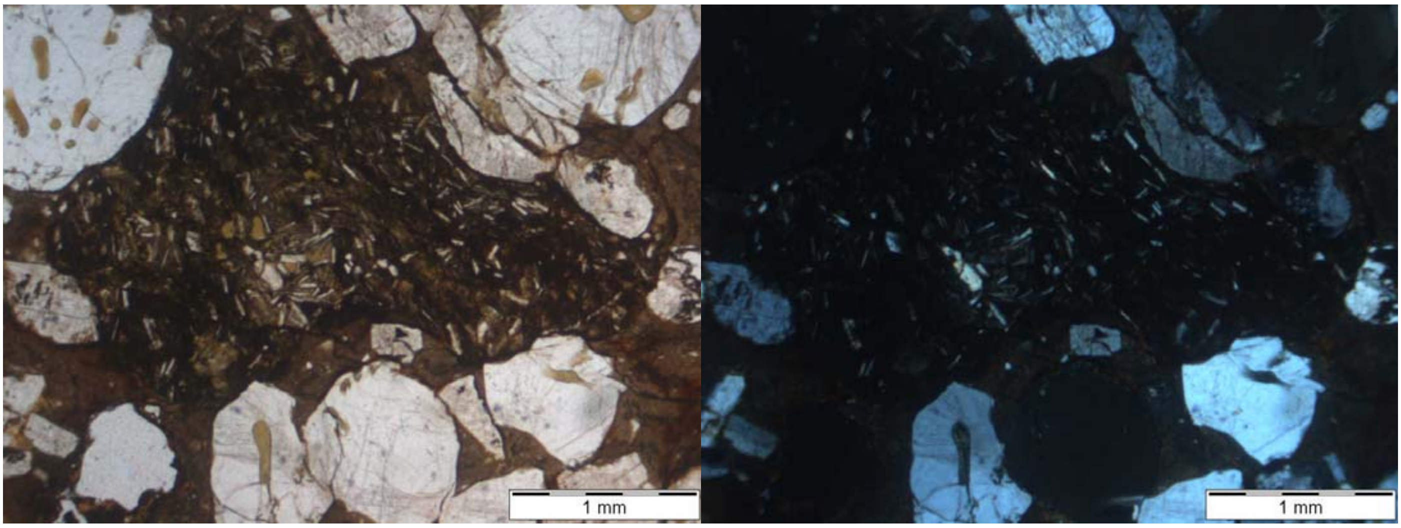


Fig. II.7.9. A possible lava fragment. Sample JM 12-41 along the mamelon 105. The image on the left is taken in plane-polarized light; the image on the right is taken with crossed polars.

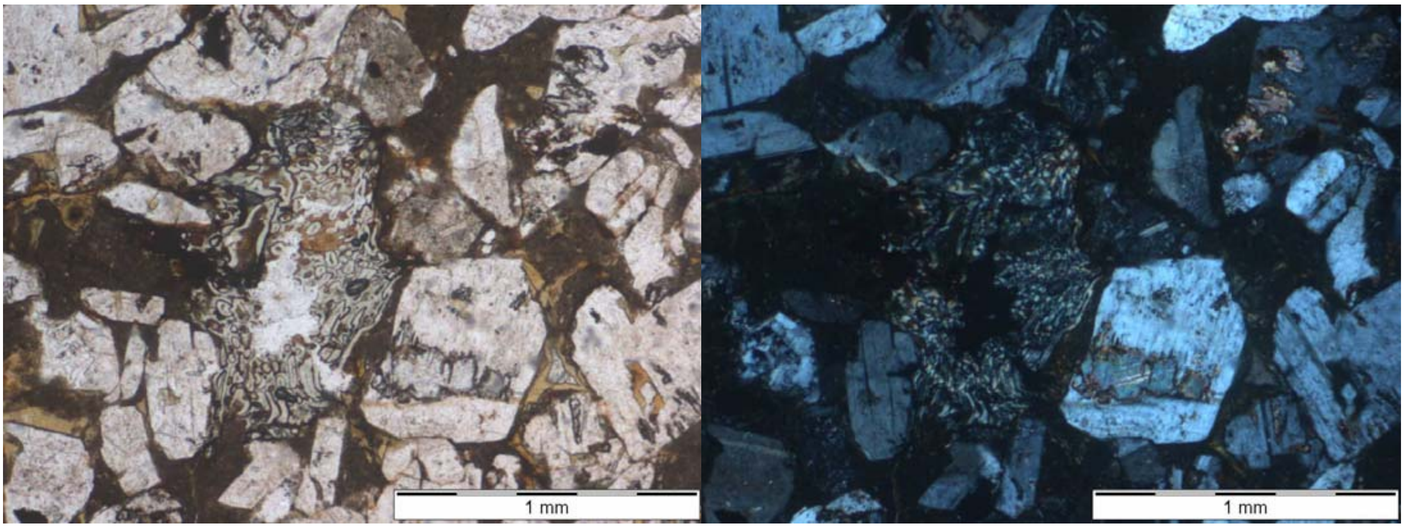


Fig. II.7.10. A possible pumice fragment. Sample JM 12-45 along the mamelon 105. The image on the left is taken in plane-polarized light; the image on the right is taken with crossed polars.

A total of 27 thin sections scattered over the three sections has been made of the "arkose": 10 thin sections along the mamelon 105, fig. II.7.1a; 10 thin sections from the abandoned quarry, fig. II.7.1b, samples JM 12-35, JM 12-36, JM 12-37, JM 12-38 are not studied due to their fine grain size; 3 thin sections from Neuville-sous-Huy, ravine 700 m E, fig. II.5.3 for the location; 4 thin sections from Neuville-sous-Huy, ravine 1200 m E, fig. II.6.3 for the location. They all share the same petrographical characteristics, hence the grouping of them. Crystals of plagioclase and quartz occur in a fine grained green-brown matrix. Plagioclase occurs more frequently than quartz in most cases. The crystals are broken. The crystals become smaller going upwards and occur less abundantly until almost only a matrix is present in the fine-grained parts. The quartz crystals are slightly rounded and sometimes contain inclusions, possibly devitrified glass (see fig. II.7.7). The plagioclase contains only albite. Chlorite is sporadically present. The green fragments, that are clearly visible by the naked eye, show a brownish colour in the thin section and it is not easy to distinguish them from the brownish matrix. Sometimes calcite is present, in many cases close to the plagioclase crystals. Small zircon crystals are sometimes present. Sedimentary rock fragments (greenish to brownish; see fig. II.7.8), possible lava fragments (see fig. II.7.9) and possible pumice fragments (see fig. II.7.10) sometimes do occur. Quartz crystals and lithic fragments occur more frequently higher up. Towards the top the rock becomes more bedded and it is doubtful if we can classify the rocks as a volcaniclastic rock as they are close to a sedimentary rock.

7.2.1.5. Discussion

The two "arkose" levels in the Parc de la Neuville, present along the mamelon 105 and in the abandoned quarry have been correlated by Michot (1932a, 1934) as one level. He saw folds along mamelon 105, a repetition of the facies between the mamelon 105 and the abandoned quarry that he connected by a fold (see fig. II3.3), and the "arkose" along the mamelon 105 and in the abandoned quarry share the same characteristics. Hence concluding that the "arkose" is the same level.

We cannot confirm the hypothesis proposed by Michot (1932a, 1934), although some of his arguments have been observed. The facies north of the "arkose" along the mamelon 105 and the abandoned quarry is the same: a centimetric to decimetric alternation of red mudstone and green, olive green to grey and dark grey mudstone. Along the mamelon 105 northern beds are required to describe folds. We always observed a southern bedding along the mamelon 105. Except at one place where it is not clear what the bedding is. On that place planar structures have been found orientated to the north and orientated to the south. Hence it is possible that Michot (1932a, 1934) interpreted the northerly direction as bedding. We have not found any arguments to say what the bedding is. Interesting is the presence, the lithology and the bedding of the southernmost outcrop along the mamelon 105 (see fig. II.3.2 referred to as belonging to outcrop 2) situated approximately 17 meters further southwards of the previous more northerly outcrop. The outcrop contains volcaniclastic rock that is coarser and comparable with these of the volcaniclastic rock just southwards of the elliptic zone along the mamelon 105. The bedding is to the south. Hence a repetition of the facies takes place along the mamelon 105. The repetition can be explained by folding or faulting but due to the lack of outcrop it cannot be observed and tested.

The horizontal distance that Michot (1932a, 1934) drew between the most northerly contact of the arkose with the mudstone along mamelon 105 and the most southerly contact of the arkose with the mudstones in the abandoned quarry is approximately 83 meters (fig. II.3.3). We have measured a distance of 132 meters, a difference of 49 meters. Hence the location of the section on the drawing of Michot (1934; fig. II.3.3) is approximately and cannot be used by great certainty to locate the different units.

Hence we cannot confirm the hypothesis proposed by Michot (1932a, 1934) that the "arkose" belongs to one level in the Parc de la Neuville. The lack of outcrop hampers to make a definite conclusion.

The deposition of the “arkose” is not easy to distinguish. It consists of badly sorted, broken crystals in a green-brown matrix. The broken nature of the crystals points to an assignment into a volcaniclastic rock. The quartz crystals are sometimes slightly rounded indicating a short transportation. The crystal content decreases upwards where the matrix becomes more dominant. The “arkose” shows affinities with an ignimbrite (Van den Haute, pers. comm., 2012).

7.2.1.6. Stratigraphical position of the “arkose”

	Type contact		Sedimentary layers		Age of the sedimentary layers	Thickness of the arkose
	below	above	below	above		
Parc de la Neuville						
Mamelon 105	Fault?	Not observed	Centimetric alternation of red, green, olive green to grey and dark grey, compact mudstone	Not observed	?	≥19.1 meters
Abandoned quarry	Incision	Fault	Grey-green compact mudstone	Green to olive green, compact, mudstone, sometimes a centimetric level of red mudstone	?	±22 meters
Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville	Following the bedding	Following the bedding	Grey, green-grey to green compact mudstone alternating with dark grey and green-grey, laminated mudstone		Below: uppermost *crispus* Biozone Above: lowermost *griestoniensis* Biozone; (lower part middle Telychian)	2.08 meters
Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville	Incision	Fault?	Dark grey to dark green-grey, sometimes laminated mudstone		Upper Telychian	3.08 meters + ±0.5 meters (?)

Table. II.7.3. Overview of the “arkose” levels of the three sections in Neuville-sous-Huy, Parc de la Neuville, ravine 700 m east of Parc de la Neuville, ravine 1200 m east of Parc de la Neuville. The type of contact below and above the “arkose” is given, the sedimentary layers that are present below and above the “arkose”, the age of these layers and the thickness of the “arkose”.

The “arkose” shares the same characteristics in the three sections and this is the reason that previous authors have grouped them. As we will show below they correspond to three (maybe four) different levels. An overview of the “arkose” levels is given in table II.7.3.

As displayed in table II.7.3 we consider the “arkose” of the three sections (in Neuville-sous-Huy, Parc de la Neuville, ravine 700 m east of Parc de la Neuville, ravine 1200 m east of Parc de la Neuville) in every section as a different level although they share more or less the same petrographical characteristics. The sedimentary layers below and above the “arkose” is different in every section. The presence of one or two different levels in the section Parc de la Neuville is discussed in chapter 7.2.1.5.

7.2.2. Keratophyre levels

The keratophyre levels occur in the sections Neuville-sous-Huy, ravine 700 m east and ravine 1200 m east of Parc de la Neuville.

7.2.2.1. Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville

A total of ten volcaniclastic layers have been discovered plus the volcaniclastic layer V6 representing the “arkose”. Two more, labeled as Va and Vb by us, than described by Vandevelde (1976). The same numbering have been used. From base to top the following volcaniclastic layers occur:

Va: Green-grey, stratified, volcaniclastic rock. The thickness is 11 cm.

Vb: Grey, strongly weathered (to a dark purple and dark brown colour), volcaniclastic rock. At the bottom it is coarser, darker in colour and stratified, to the top it becomes finer, paler and not stratified. The thickness is 70 cm.

V1: In the original definition of V1 by Vandevelde (1976) the volcaniclastic layer is not subdivided. We could observe that it consists of multiple layers of volcaniclastic rock and mudstone. From base to top:

- Grey volcaniclastic rock, often weathered to a dark purple colour. It has rusty patches and white, green and black crystals. The thickness is 60 cm.

- Green to grey mudstone with a thickness of 7 cm.

- A volcaniclastic rock with the same characteristics as from the base and with a minimal thickness of 105 cm.

- A subvertical fault occurs obscuring the succession.

- 15 cm of mudstone that could also be of a volcaniclastic origin.

- 90 cm of volcaniclastic rock. It consists of hard, not stratified rock and soft, stratified rock. The hard massive rock has the same characteristics as the volcaniclastic rocks below but is sometimes more green. The stratified volcaniclastic rock is brown-green to green-grey, probably originally green-grey. It consists of rare crystals and rock fragments (a.o. small pebbles) in a dominantly clayey matrix. The stratified rock becomes more and more dominant going upwards.

- Grey, quartzitic mudstone with a thickness of 25 cm

- 5 cm of stratified volcaniclastic rock with the same characteristics as these below the mudstone.

- Dark grey, compact and dark grey and green-grey, laminated mudstones with a thickness of 7 cm.

- 35 cm of mainly stratified beds, with the same characteristics as below, and hard non-stratified beds with the same characteristics as these from the base.

V2: At the base it is weathered to a clay/ clayey layer. It is a grey, hard, volcaniclastic rock, mostly weathered, with rusty patches and white, green and black crystals. It is 40 cm thick. It is exposed along the eastern path and in the brooklet.

In between V2 and V3 a 5 cm (along the eastern pathway), and a approximately 6 cm (along the brooklet) thick layer of green-grey mudstone do occur (see fig. II.7.11).

V3: A grey, hard, volcaniclastic rock with rusty patches and white, green and black crystals. It has a minimal thickness of 75 cm along the eastern path. Along the brooklet it is also exposed with a minimum thickness of 125 cm and interrupted by a fault.

The exposures of Va, Vb, V1, V2 and V3 along the eastern pathway are poorly exposed.

V4: Weathered, grey, fine-grained volcaniclastic rock with rusty patches. The thickness is 170 centimeters.

V5: Can be divided into multiple parts with each own characteristics. From base to top:

- Grey to greenish, fine-grained, massive rock with rusty patches and crystals up to 1 mm in size. Sometimes elongated, non determinable forms are present, the same as in the above layer. It is 47 cm thick.

- Stratified and quite soft with white and beige, elongated minerals. Green, brown and purple crystals are present. The thickness, 25 cm, can only be given approximately, because of the presence of faults.

- Grey to greenish rock with dark crystals, rusty patches and the presence of brown and white crystals. Towards the upper part of the rock, via a transition zone, becomes stratified, paler and softer. Further upwards it becomes also paler with a fining upwards trend. At the top it is fine-grained possessing some coarser parts, possible crystals. Small pebbles, quite rare, are found in this stratified rock. In the stratified part a spherical object (of a few cm) is present without any stratification and crystals without any colour. At the base of this bed it is massive with a thickness of 80 cm going upwards via a transition zone, 30 cm thick, into a softer and stratified rock 125 cm thick.

V7: The volcaniclastic layer can be divided into three parts with a total thickness of 210 cm. The base of V7 is digging approximately 1 cm in the underlying mudstones indicating normal polarity. From base to top we observe:

- Green-grey, sometimes stratified volcaniclastic rock with visible grains and often weathered to dark yellow colour. It is 63 cm thick.

- Grey, fine-grained, aphanatic volcaniclastic rock. It is 72 cm thick.

- Green grey volcaniclastic rock sometimes stratified (alternation of harder and softer beds) and in most cases weathered to a white and/or dark yellow colour. The harder beds are green-grey and fine-grained. But it is also white to dark yellow with rusty dots. The softer beds are white to yellow, always weathered. It is bounded upwards by a fault and hence a minimal thickness of 75 cm.

V8: The volcaniclastic layer is outcropping mainly in the bedding of the brooklet. It can be divided into different parts with a total thickness of 913 cm. From base to top we observe:

- Grey, medium-grained volcaniclastic rock with phenocrysts. It is 24 cm thick.

- Grey, very hard and very fine-grained rock. It is 45 cm thick.

- Grey to light grey, fine-grained volcaniclastic rock with many rusty patches (possibly weathered phenocrysts). At the base and at the top grey, stratified volcaniclastic rock occurs. It is 28 cm thick.

- Grey, very hard and very fine-grained rock. It is 26 cm thick.

- Grey-green to grey, hard, fine-grained, aphanatic, volcaniclastic rock with sometimes rusty patches. More stratified beds, that are softer, do also occur that are (light) grey to greenish and occur more going upwards. The beds that are not stratified and these that are stratified are not tied to certain beds and the thicknesses can change laterally (oblique to the bedding). The thickness is 734 cm thick.

- Alternation of grey, hard mudstone (22-7-15 cm) and soft, stratified probably volcaniclastic rock (5-6-1 cm).

V9: Light grey-green, hard, fine-grained, aphanatic volcaniclastic rock (see fig. II.7.12). Some beds are locally weathered to a clayey layer or are softer and more shaly. These weathered layers are not bounded to certain beds and a little bit oblique to the bedding. The lower and upper boundary is bounded by faults. Hence there should be a minimum thickness of 186 cm.

The characteristics of the volcaniclastic layers V1, V2 and V3 are quite the same based on the field observations. The volcaniclastic beds V7 (for the upper part), V8 and V9 show a common characteristic. They have hard, quartzitic beds with in between softer layers. These softer layers are often slightly oblique to the bedding of the rock.

Fig. II.7.11. Outcrop of the volcaniclastic layers V2 and V3 along the brooklet. Note the presence of the thin mudstone layer packed between the volcaniclastic layers. On the right a detail of the mudstone is visible. The mudstone is packed between the volcaniclastic layers V2 and V3. The contact is not straight but undulating.

Fig. II.7.12. The northly dipping volcaniclastic layer V9 with clayey layers in between that are a little oblique to the bedding. The volcaniclastic layer is bounded between faults.

7.2.2.2. Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville

We describe a total of three volcaniclastic layers (Vα, Vβ, and Vδ) plus the "arkose" (Vγ, described above), one more in comparison with Maes (1976) and Maes *et al.* (1978). As already mentioned above we use a different numbering in comparison with previous authors. The layers are described as follows:

Fig. II.7.13. Left. Outcrop of Vα and the covering mudstones. Right. Detail of the presence of the two hard spheroidal objects at the top of part 3 of Vα.

Vα: The volcaniclastic layer is present along the pathway (see fig. II.7.13) and was not described by Maes (1976). It can be divided into 3 parts. From base to top:

- Part 1: Probably a grey fine-grained rock of which the volcaniclastic or sedimentary origin is unsure due to strong weathering to almost a clay. The thickness is estimated at 56 cm.

- Part 2: Grey, hard, massive fine-grained volcaniclastic rock. A clayey layer is present 37 cm above the base. The thickness is estimated at 67 cm.

- Part 3: Green-grey, stratified volcaniclastic rock. It is strongly weathered to a whitish or brownish colour. White, orange and black crystals do occur. In the uppermost part two hard spheroidal objects are found (see fig. II.7.13), with the same lithology as part 2. The thickness is estimated at 50 cm. At the top a fault is present.

The total observed thickness of Vα is estimated at 173 cm, with no observation of the lower contact and a fault at the top. The bedding is not clearly visible.

Vβ: Grey, hard volcaniclastic rock with rusty patches. This volcaniclastic layer is squeezed in between faults. Its minimal thickness is 63 cm. In lithology it is comparable with V2, V3 and V4 of the section of Neuville-sous-Huy, ravine 700 m E.

Vδ: Grey, hard, fine grained volcaniclastic rock containing small cavities filled up with white to colourless crystals. This volcaniclastic layer is present in a small outcrop approximately 6 m topographically higher of the outcrop where samples JM 10-37 and JM 10-38 have been taken (see fig. II.6.3). The exact position of this volcaniclastic layer is unknown. It can be possibly correlated with volcaniclastic layer Vβ by sharing the same lithology. It is comparable with V2, V3 and V4 of the section of Neuville-sous-Huy, ravine 700 m E.

7.2.1.4. Petrographical study of the keratophyre levels

A preliminary petrographical study of twenty thin sections are studied on the keratophyre levels of the section of Neuville-sous-Huy, ravine 700 m E: one from V2, three from V3, five from V5, four from V7, six from V8 and one from V9; see fig. II.5.6 for the location. The study of these layers by means of thin sections is difficult as in most cases only a green brown matrix can be observed and the crystals are small. Some larger crystals are present mainly plagioclase (only albite) and alkali feldspar. Chlorite and devitrified glass is present in most samples. Calcite and dolomite (containing iron) is also present in some samples.

8. Lithostratigraphical units of the Silurian of the Condroz Inlier and biostratigraphy with chitinozoans

Almost all the stratotypes of the defined Silurian lithostratigraphical units of the Condroz Inlier have been visited and studied. The outcrops are sampled for chitinozoans by us. Below the lithological and chitinozoan results of these outcrops will be discussed. The discussion on the lithostratigraphy will be discussed in chapter III.1. An additional section is studied and discussed in chapter 8.8 to obtain more information about the sediments of the middle Wenlock. The systematical discussion of all the samples discussed below together with the plates have been grouped together at the end of this chapter in chapter 8.9.

8.1. Dave Formation

The term Dave Formation has been created by Michot (1932b) as “schistes de Dave”, emended and enlarged by Michot (1954) as “assise de Dave”. Verniers *et al.* (2001) uses the first time the Dave Formation. Vanmeirhaeghe (2006b) has restricted the definition of the formation to the original sense by Michot (1932b). We will consider and review the definition of Michot (1932b) of the Dave Formation in the type locality.

8.1.1. Earlier studies

Michot (1932b), rewrites the same observations in 1934, describes in Dave (belonging to the municipality of the city of Namur) three different outcrops where he has found graptolites. We labeled these outcrop as 1, 2 and 3. For an overview of his observations we refer to table II.8.1 and fig II.8.1 for the location of these outcrops.

Outcrop	Lithology	Graptolites	Graptolite Biozone
Outcrop 3	Bluish to blackish, slightly sandy shale	*Orthograptus bellulus*	*gregarius – convolutus* (Michot, 1932b) top *gregarius - convolutus – sedgwickii* (Michot, 1934)
Outcrop 2	Blackish (sometimes slightly greenish) shale	*Monograptus nudus* *Climacograptus scalaris*	*sedgwickii - turriculatus*
Outcrop 1	Bluish-blackish (sometimes slightly greenish) shale	*Monograptus vomerinus*, *var. crenulatus* *Monograptus priodon*	*crenulata*

Table II.8.1. Overview of the observations of Michot (1932b, 1934) of the three outcrops of the Dave Formation.

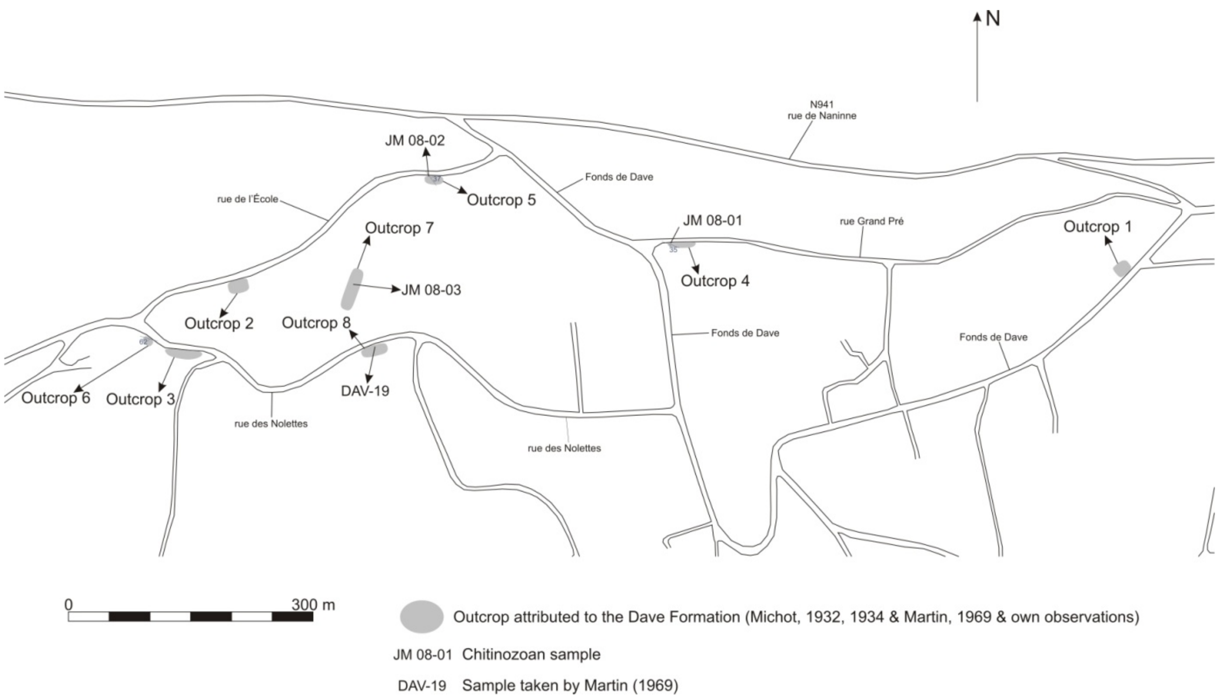


Fig. II.8.1. Map of Dave with the location of the outcrops and the samples.

He summarizes that there are bluish to blackish, slightly sandy shales with three graptolite levels occurring from the middle-upper Aeronian to the middle Telychian, as indicated in table II.8.1, belonging to the Dave Formation.

8.1.2. New data

8.1.2.1. Lithological results

From the outcrops that Michot (1932b, 1934) has described, only outcrop 3 is still accessible. Outcrop 1 was a temporary outcrop created by the construction of a house; outcrop 2 disappeared due to a construction of a house on that place. Delcambre & Pingot (in press), while restudying the area for the new detailed geological map of the region, found five outcrops in this region corresponding to the Dave Formation, in the sense of Michot (1932b). One of the five outcrops, outcrop 3, was already described by Michot (1932b, 1934). The other four outcrops have been labeled as outcrop 4 to 7 (see fig. II.8.1). We have visited and studied these five outcrops.

The five outcrops, outcrop 3 to 7, contain dark grey, slightly greenish, mudstone which can be sometimes slightly coarser. The mudstone contains small rusty patches orientated parallel to the bedding of the rock and small rusty spheroids smaller than 1 mm. These small rusty spheroids are probably the result of weathering of pyrite.

8.1.2.2. Chitinozoan results and discussion on bio- and chronostratigraphy

Three samples were studied, one of outcrop 4, one of outcrop 5 and one of outcrop 7 giving a total of 262 chitinozoans. Outcrop 3, described by Michot (1932b, 1954), was not sampled by us because of the poorly exposure of the outcrop. The abundance of the chitinozoans in sample JM 08-01 (outcrop 4) is lowest with 0.62 chitinozoans per gram of rock. In sample JM 08-02 (outcrop 5) and sample JM 08-03 (outcrop 7) it is respectively 5.05 and 6.26 chitinozoans per gram of rock. The chitinozoans are poorly to moderately well preserved with the poorest preservation in sample JM 08-01.

In sample JM 08-01 only one *Conochitina* sp. and some undeterminable chitinozoans could be obtained. Sample JM 08-02 contains *Cyathochitina* cf. *calix*, *Salopochitina*? sp. 1, *Salopochitina*? spp, one specimen of *Sagenachitina* sp. 1, one specimen of *Sagenachitina* sp. and one specimen of *Siphonochitina* sp. Sample JM 08-03 contains *Conochitina chydaea*, *Euconochitina vulgaris* and *Siphonochitina* spp.

Outcrop	Sample number	*Conochitina* spp.	*Cyathochitina* cf. *calix*	*Salopochitina*? sp. 1	*Sagenachitina* sp. 1	*Desmochitina* spp.	*Calpichitina* spp.	*Sagenachitina* spp.	*Belonechitina* spp.	*Cyathochitina* spp.	*Siphonochitina* spp.	*Salopochitina*? spp.	*Conochitina chydaea*	*Euconochitina vulgaris*	*Eisenackitina* sp. 1	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
7	JM 08-03	11				1	1		4		5		11	7	2	99	141	22.52	6.26
5	JM 08-02	1	4	11	1	4	7	1	4	2	1	4				68	108	21.38	5.05
4	JM 08-01	1														12	13	20.89	0.62
Total		13	4	11	1	5	8	1	8	2	6	4	11	7	2	179	262	64.79	4.04

Table II.8.2. Chitinozoan results of the outcrops at Dave.

The chitinozoan content of sample JM 08-01 does not allow any bio- and chronostratigraphical attribution.

The other two samples have interesting assemblages of chitinozoans although the identification is in most cases not to species level.

Sample JM 08-02 contains the genera *Sagenachitina* and *Siphonochitina* that range from the upper part of the Lower Ordovician to the Middle Ordovician (Paris, 1990; Paris *et al.*, 1999; Paris & Verniers, 2005). Hence we can say that sample JM 08-02 can be placed in the upper part of the Lower Ordovician to the Middle Ordovician.

Sample JM 08-03 contains also the genus *Siphonochitina* giving a range of the upper part of the Lower Ordovician to Middle Ordovician (Paris, 1990; Paris *et al.*, 1999; Paris & Verniers, 2005). It contains the long ranging Ordovician chitinozoan *Conochitina chydaea*. *Euconochitina vulgaris* starts to occur on the boundary of the Lower and Middle Ordovician (middle Arenig) up to the upper part of the Middle Ordovician (middle Darriwillian, lower Llanvirn; Jenkins, 1967, Paris, 1981). It implies that sample JM 08-03 ranges from the boundary of the Lower and Middle Ordovician up to the middle Darriwillian.

8.1.2.3. Discussion

Although our samples do not come from the outcrops described by Michot (1932b, 1934) as the type locality of the formation, they belong most likely to the Dave Formation, defined by this author. The outcrops share all the same lithology and can be placed on the geological map of Michot (1934) belonging to the definition of the Dave Formation. Our samples can be dated to the upper part of the Lower Ordovician up to the Middle Ordovician and hence are certainly not Llandovery in age. Interesting to note is that Martin (1969a) has studied a sample in Dave (sample DAV-19, outcrop 8) that should also belong to the Dave Formation according to the geological map of Michot (1934). She concludes that the acritarchs from this sample belong to sediments of Middle Ordovician in age corroborating our observations with the chitinozoans. The graptolite identifications of Michot (1932b, 1934) can be questioned as they contradict with our results.

There are two lithostratigraphical units of the central Condroz Inlier to which we can assign the rocks in the outcrops described as the Dave Formation (Vanmeirhaeghe, 2006b): the Huy Formation and the Chevreuils Formation. The Huy Formation consists of slightly micaceaous dark grey or black mudstone, with millimetric fine grained, grey siltstone laminae and a few thin (max. 5 cm) fine-grained sandstone beds. It has an age of middle Darriwilian (early Llanvirn) according to Vanmeirhaeghe (2006b). The Chevreuils Formation consists of dark grey to black, micaceous mudstones and siltstones, sandstones, often burrowed and containing pyrite. It has an age of late Darriwillian (late Llanvirn) to early Sandbian (early Caradoc) according to Vanmeirhaeghe (2006b). Hence we cannot assign easily our outcrops to one of these two lithostratigraphical units. Only long-ranging chitinozoans do occur in our samples together with some not yet described specimens, as is the case in the Chevreuils Formation (Vanmeirhaeghe, 2006b). These arguments favor to place the outcrops in the Chevreuils Formation.

8.2. Naninne Formation

The term Naninne Formation has been created by Malaise (1900) as “schiste et psammite de Naninne”. Malaise (1910) uses the term “assise de Naninne” and Verniers *et al.* (2001) uses for the first time Naninne Formation. The stratotype is defined in the village of Naninne (belonging to municipality of the city of Namur) in the rue des Flawnées 27 m to the north of the crossroad of the rue des Flawnées and the rue de la Sapinière (Michot, 1934 and own observations; see also map fig. II.8.2).

8.2.1. Earlier studies

Michot (1932b, 1934) describes this outcrop as follows: reddish, finely laminated, sandy shales with intercalated sandstones. He found two levels very rich in graptolites. The first level contains the graptolites: *Cyrtograptus Murchisoni*, *Monograptus priodon*, *M. vomerinus*, *M. vomerinus* var. *basilicas*, *M. riccartonensis*, *M. capillaceus*, *Retiolites Geinitzianus* and an orthocone nautiloid *Orthoceras* sp. He assigns this level to the *Cyrtograptus murchisoni* Biozone. In the following level he finds: *Monograptus riccartonensis*, *M. capillaceus*, *M. vomerinus*, *M. vomerinus* var. *basilicus*, *M. priodon*. He places this level in the *Monograptus riccartonensis* Biozone.

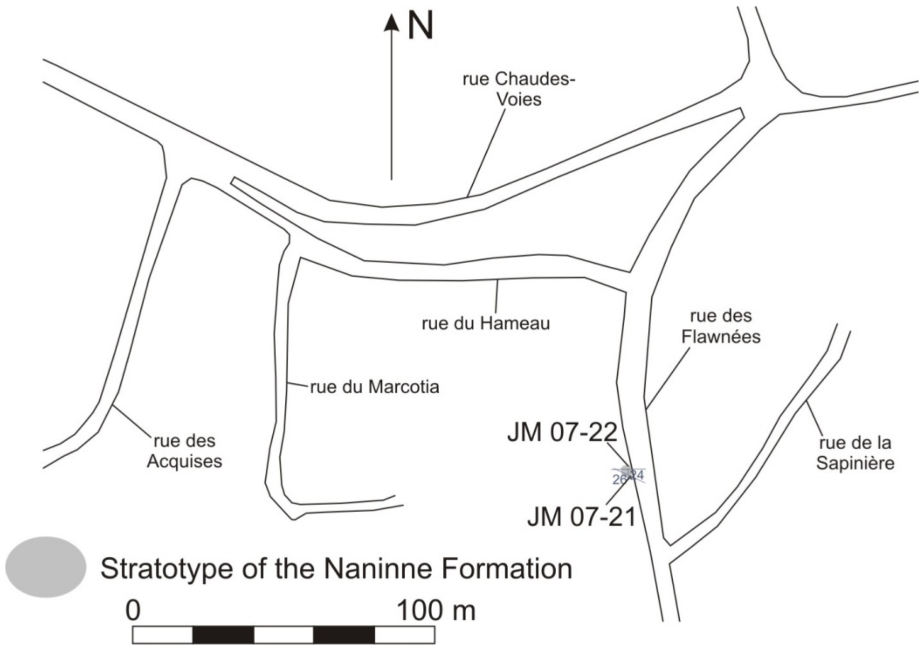


Fig. II.8.2. Map of Naninne with the location of the stratotype of the Naninne Formation.

8.2.2. New data

8.2.2.1. Lithological results

Our observations of this outcrop confirms more or less the description of Michot (1932b, 1934). We observed grey, finely laminated mudstone with intercalations of grey, compact, coarser mudstone. The rocks are in most cases very weathered, especially the shales are brownish weathered. The observed thickness in the outcrop is approximately 3.5 meters.

8.2.2.2. Chitinozoan results and discussion on bio- and chronostratigraphy

Sample number	*Conochitina* cf. *proboscifera*	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
JM 07-22	1	5	6	20.98	0.29
JM 07-21			0	28.07	0.00
Total	1	5	6	49.05	0.12

Table II.8.3. Chitinozoan results of the stratotype of Naninne.

Two samples have been studied: JM 07-21 and JM 07-22. Sample JM 07-22 contains 6 chitinozoans; sample JM 07-21 is barren. The abundance is low with sample JM 07-22 containing 0.29 chitinozoans per gram of rock. The chitinozoans are very poorly to poorly preserved. The cause of this poor preservation is probably due to the fact that the rocks are strongly weathered.

In sample JM 07-22 one specimen of *Conochitina* cf. *proboscifera* occurs. *Conochitina proboscifera* occurs in eastern Baltica from the upper Telychian to the lower Sheinwoodian (Nestor, 2012). This time range is not in contradiction with earlier findings of Michot (1932b, 1934).

The recorded chitinozoans do no contradict the graptolite identifications by Michot (1932b, 1934) and the rocks belong to the *Cyrtograptus murchisoni* Biozone up to the *Monograptus riccartonensis* Biozone.

8.3. Jonquoi Formation

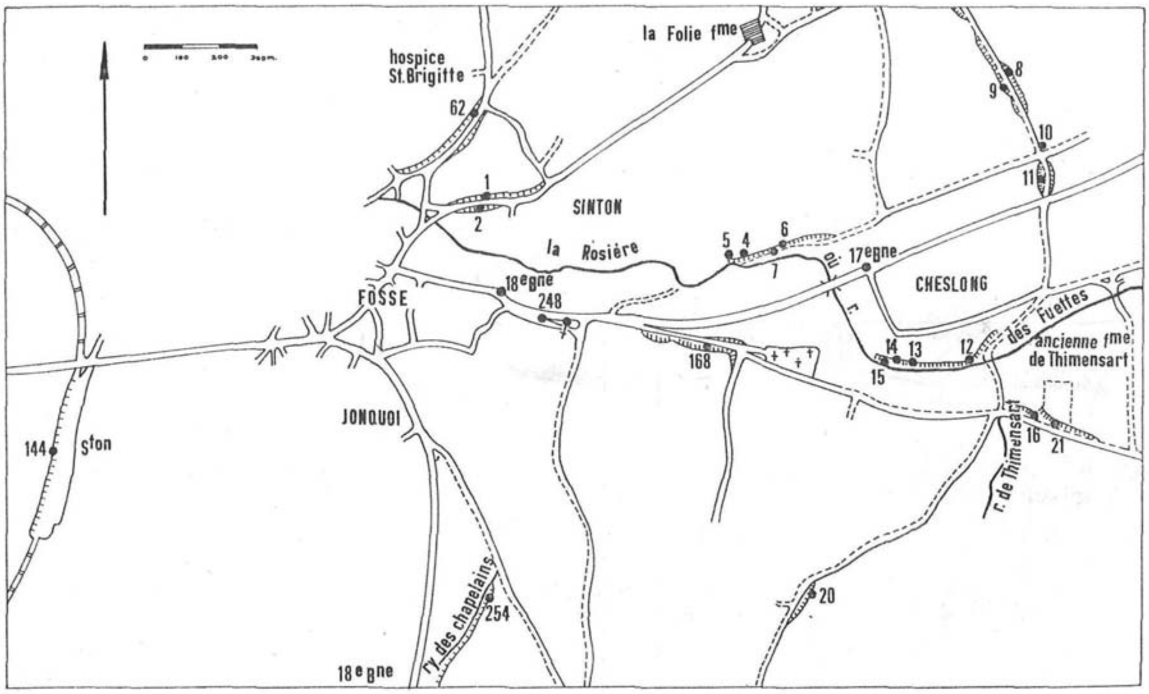


Fig. II.8.3. Map of the region of Fosses-la-Ville drawn by Martin (1969a) with her samples taken in the region. From Martin (1969a).

The term Jonquoi Formation has been created by Michot (1954) as “assise de Jonquoi”. Verniers *et al.* (2001) uses for the first time Jonquoi Formation. Michot (1954) describes it as green shales and sandy shales with rare thin intercalations of clayey sandstone. They are classified above the Biozone *Monograptus riccartonensis* and below the *Neodiversograptus nilssoni* Biozone.

The stratotype of the Jonquoi Formation is not exactly known. It is situated in the hamlet of Jonquoi, near Fosses-la-Ville (Martin, 1969a). The place name Jonquoi has been mentioned on a map drawn by Martin (1969a) (see fig. II.8.3) but is not found on the topographic map. Three places with outcrops belonging to the Jonquoi Formation were indicated by Martin (1969a) in Fosses-la-Ville: FOS-144 (along an old railway bed close to the old station of Fosses-la-Ville) and FOS-16 and FOS-21 (situated along the northern flank of a small road just east of Ruisseau de Thimensart).

8.3.1. Earlier studies

The outcrop of FOS-144 have been described by Malaise (1880) as follows. Along the railway bedding weathered blackish shale occur. The weathering causes the shale to take a yellowish colour. Folds are present with the bedding dipping to north, followed by dips to the south and again dips to the north without mentioning the exact location. Michot (1934) describes the rocks from this outcrop only briefly as follows: green shales without any folds, contradicting the description of Malaise (1880), and a thickness of approximately 300 meters.

The outcrops of FOS-16 and FOS-21 were briefly mentioned by Malaise (1880) as nodular shales.

8.3.2. New data

8.3.2.1. Lithological results

The outcrop containing samples FOS-16 and FOS-21 of Martin (1969a) was preliminary studied by us (outcrop 2, see fig. II.8.4). The outcrop is small and occurs in the northern flank of a small road. It consists of green-grey to olive green, micaceous, sometimes laminated mudstone. The mudstone is sometimes a bit coarser up to coarse mudstone.

8.3.2.2. Chitinozoan results and discussion on bio- and chronostratigraphy

Sample number	*Conochitina claviformis?*	*Eisenackitina* cf. *inanulifera*	*Angochitina* spp.	*Conochitina* spp.	*Belonechitina* spp.	*Calpichitina* spp.	*Desmochitina* spp.	*Cingulochitina* spp.	*Bursachitina* spp.	*Eisenackitina* spp.	*Ancyrochitina* spp.	*Sphaerochitina* spp.	*Tanuchitina* spp.	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
JM 08-16			2	4	2	1	14			1	1		1	24	50	32.62	1.53
JM 08-15	1	1	5	5	8	1	8	3	1	2	3	1		38	77	30.16	2.55
Total	1	1	7	9	10	2	22	3	1	3	4	1	1	62	127	62.78	2.02

Table II.8.4. Chitinozoan results of outcrop 2, Fosses-la-Ville outcropping the Jonquoi Formation.

Two samples have been studied from outcrop 2 on their chitinozoan content: JM 08-15 and JM 08-16 (see table II.8.4). They contain respectively 77 chitinozoans and 50 chitinozoans and an abundance of respectively 2.55 and 1.53 chitinozoans per gram of rock. The chitinozoans are poorly preserved and no species could be determined.

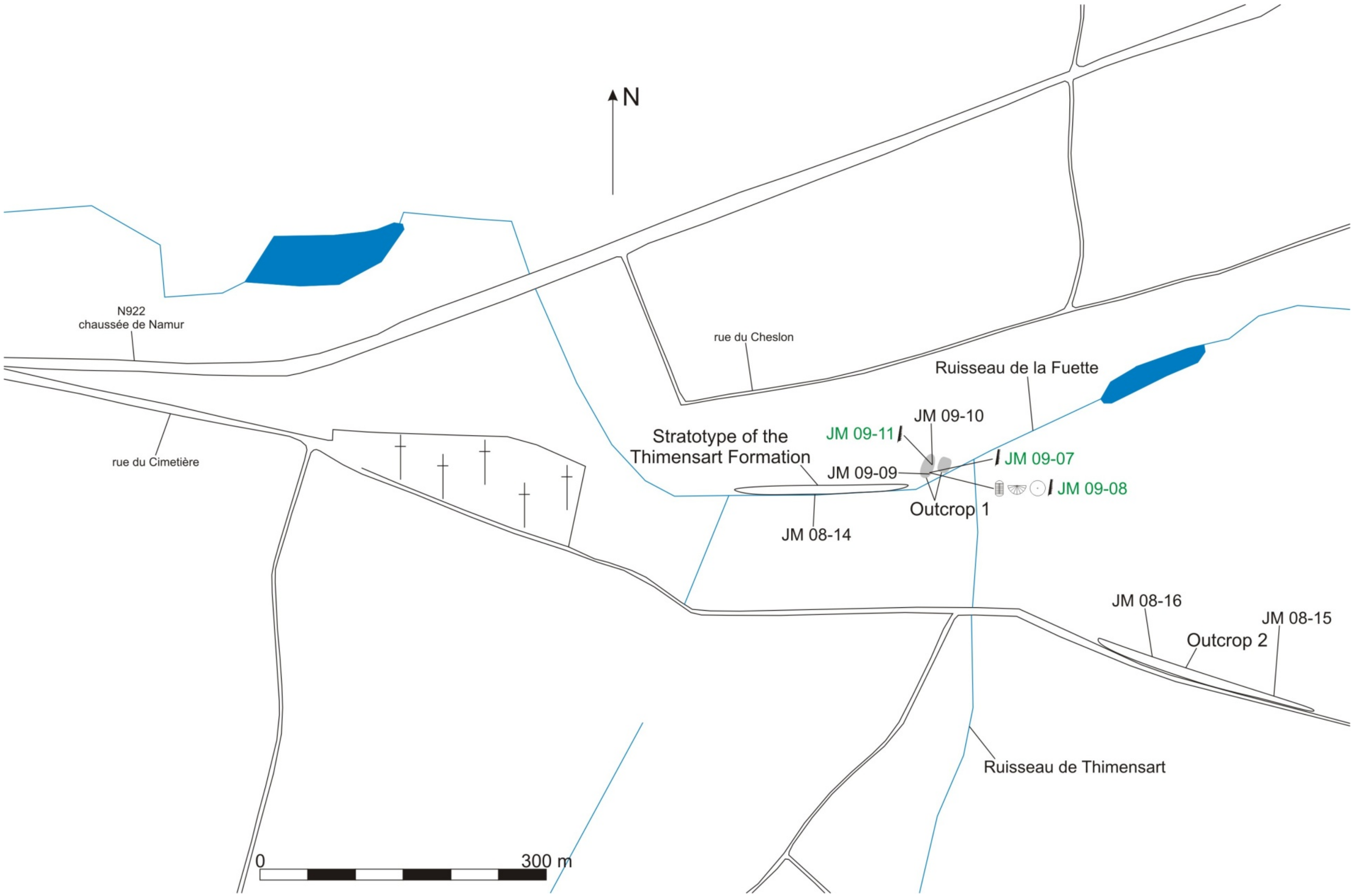


Fig. II.8.4. Map of Fosses-la-Ville with the location of the studied outcrops and the samples.

In sample JM 08-15 one specimen of *Conochitina claviformis*? and one specimen of *Eisenackitina* cf. *inanulifera* occurs. These specimens are only determined in open nomenclature. Hence we cannot use these specimens to assign an age to the rocks. Noteworthy is the presence of several specimens of *Angochitina* spp., unfortunately they cannot be identified to species level.

8.4. Thimensart Formation

The term Thimensart Formation has been created by Malaise (1900) as “schiste et psammite de Thimensart”. Malaise (1910) uses the term “assise de Thimensart” and it was emended by Michot (1954). Verniers *et al.* (2001) uses for the first time Thimensart Formation. The stratotype lies on the right bank of the Ruisseau de la Fuette just south of the place called “Le Cheslon” (Martin, 1969a).

8.4.1. Earlier studies

Malaise (1887, 1890, 1900) describes finely laminated shale with a rusty tint near the old farm of Thimensart. He found *Monograptus colonus*, *M. roemeri* and *M. nilssoni* and attributed them to the *Monograptus nilssoni* Biozone. Lassine (1913a) has found the following graptolites at the same locality: *Monograptus varians* and *Monograptus nilssoni*. They indicate the lower Ludlow according to him. Michot (1934) found the same level along the Ruisseau de la Fuette with the following graptolites: *Monograptus colonus* and *Monograptus dubius*.

8.4.2. New data

8.4.2.1. Lithological results

The outcrops along the Ruisseau de la Fuette are scarce (see fig. II.8.4). We could only find two small outcrops. One of them contains grey, laminated mudstone sometimes slightly coarser.

In the northern prolongation of the confluence of the Ruisseau de Thimensart and the Ruisseau de la Fuette a sunken small road exposes at both sides rocks (outcrop 1 on fig. II.8.4). It consists of the same lithology as along the Ruisseau de la Fuette. Brown laminae do occur. We found graptolites, crinoids, trilobites and brachiopods in the laminated levels.

8.4.2.2. Chitinozoan results and discussion on bio- and chronostratigraphy

Three samples have been studied on their chinozoan content (see table II.8.5): one along the Ruisseau de la Fuette (JM 08-14) and two from the sunken small road (JM 09-09 and JM 09-10). The chitinozoans in sample JM 08-14 are very poorly preserved with an abundance of 0.20 chitinozoans per gram of rock. The specimens could not be identified to genus level. The chitinozoans from the sunken small road are better preserved but still poorly. Samples JM 09-09 and JM 09-10 have respectively abundances of 0.34 and 1.12 chitinozoans per gram of rock.

Sample number	*Ancyrochitina* spp.	*Ancyrochitina* cf. *desmea*	*Conochitina* spp.	*Angochitina* spp.	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
JM 09-10	15	1	1	1	5	23	20.54	1.12
JM 09-09	1				6	7	20.63	0.34
JM 08-14					4	4	20.20	0.20
Total	16	1	1	1	15	34	61.37	0.55

Table II.8.5. Chitinozoan results of the samples belonging to the Thimensart Formation, Fosses-la-Ville.

Almost all the specimens could only be determined to genus level. Only in sample JM 09-10 one specimen of *Ancyrochitina* cf. *desmea* occurs. *Ancyrochitina desmea* is a species that occurs in eastern Baltica from the middle Gorstian to the upper Gorstian (Nestor, 2009 & 2012). Due to the insufficient preservation of the specimen we cannot assign it without doubts to this species.

8.4.2.3. Graptolite results and discussion with the bio- and chronostratigraphy with chitinozoans

Three graptolite levels have been found in the sunken small road: JM 09-07, JM 09-08 and JM 09-11. The graptolites are studied and identified by Prof. Dr. Petr Storch (Institute of Geology AS CR, Prague, Czech Republic). The results of the identifications is given in table II.8.6.

Graptolite level / sample number	*Pristiograptus* spp.	*Saetograptus chimaera*	*Pristiograptus dubius frequens*	*Colonograptus roemeri*	*Bohemograptus bohemicus*	crinoid columnals	small articulate brachiopod	Graptolite biozonation
JM 09-11	X				X			lower part *chimaera-scanicus*
JM 09-08		X	X	X		X	X	
JM 09-07	X							

Table II.8.6. Graptolite results of Fosses-la-Ville, Thimensart Formation.

The graptolites of the sunken small road belong to the lower part of the *Saetograptus chimaera-Lobograptus scanicus* Biozone of the middle Gorstian.

The outcrop of the sunken small road have an age of middle Gorstian. The chitinozoans from the two samples of this outcrop do not contradict this age assignment.

8.5. Criptia Group

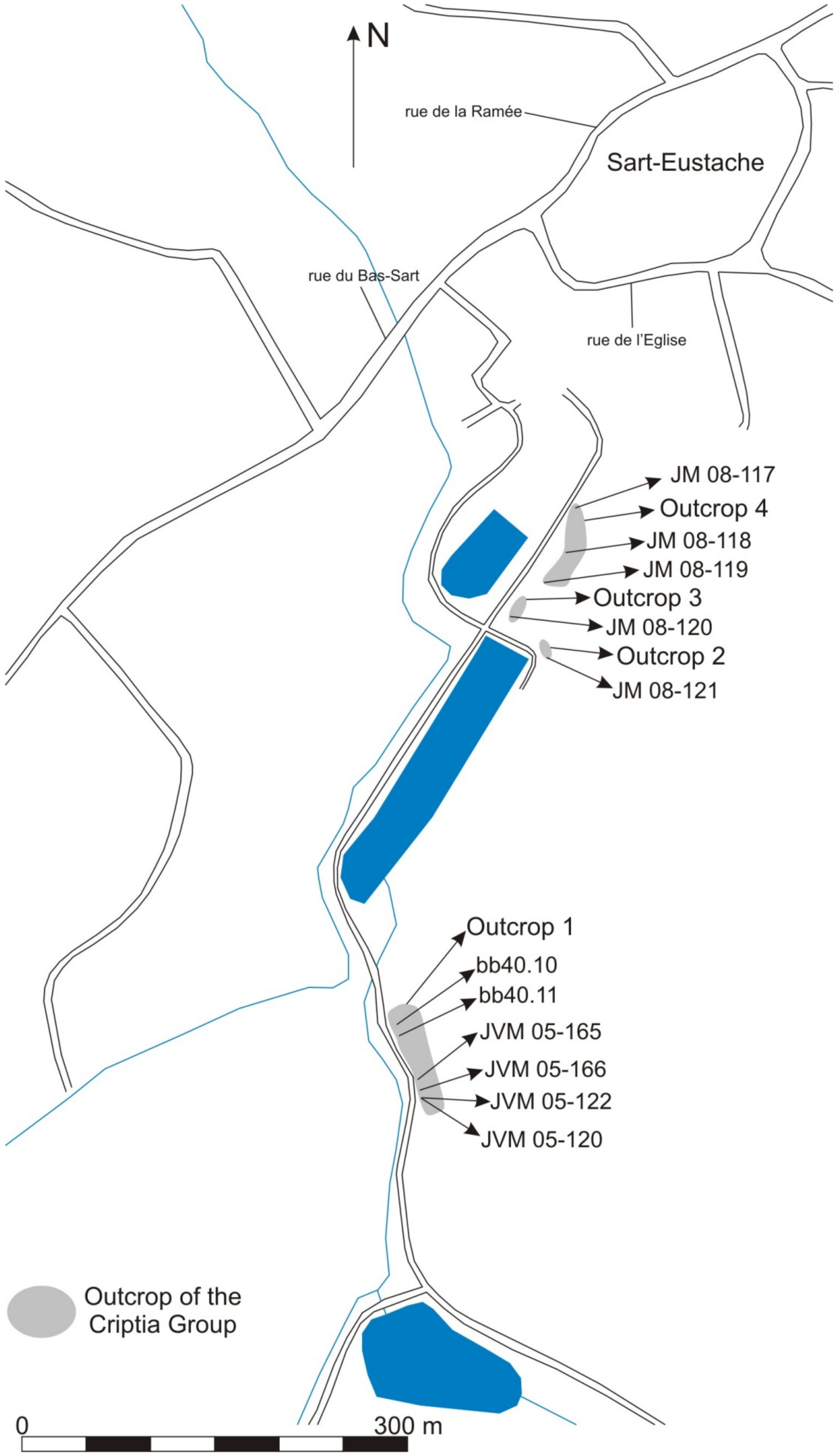


Fig. II.8.5. Map of Sart-Eustache with the location of the studied outcrops of the Criptia Group and the samples

Rocks from the "Plateau de Criptia" were described by Michot (1928) as the "schistes de Criptia". The unit has been defined by Delcambre & Pingot in Verniers *et al.* (2001) as Criptia Group and the resulting geological map of Delcambre & Pingot (2004). The stratotype of the Criptia Group has been defined by Vanmeirhaeghe (2006b) in the Parc de Sart-Eustache, Sart-Eustache in the eastern limb of the valley of the Ruisseau de l'Étang du Diable between the limit with the Génicot Formation (approximately 155 m north of the southern stone entrance of the Parc) and the church of Sart-Eustache (see fig. II.8.5).

8.5.1. Earlier studies

Billiaert (2000) briefly mentions the outcrops of the Criptia Group in the Parc de Sart-Eustache. They consist of green-grey shale and are often deformed. He took 2 samples (bb40.10 and bb40.11) from the lower part of the Criptia Group for chitinozoan study. He found *Conochitina electa* (in sample bb40.11), *Belonechitina postrobusta* (in sample bb40.11) and *Conochitina iklaensis* (in sample bb40.11 and bb40.10) and assigned an age of upper Rhuddanian to Aeronian for the lower part of the Criptia Group.

Vanmeirhaeghe (2006b) confirms the description that the Criptia Group consists of green-grey mudstone. The contact with the underlying Génicot Formation is sharp. He restudied the samples from Billiaert (2000) and studied four more samples. He concluded that *Conochitina electa* was misidentified and *Belonechitina postrobusta* was too prematurely identified in the samples from Billiaert (2000). He identifies them as *Belonechitina* cf. *postrobusta* besides specimens of *Anycrochitina ancyrea*, *Spinachitina* sp. A, *Spinachitina* spp. and *Cyathochitina* spp. Vanmeirhaeghe (2006b) suggests that the Criptia Group should be younger than the underlying Génicot Formation of middle Aeronian in age. A (late) Llandovery age is proposed although a possible Wenlock to early Ludlow age is not excluded by Verniers *et al.* (2001).

8.5.2. New data

8.5.2.1. Lithological results

The outcrops (outcrop 1, 2, 3 and 4) that have been studied in the Parc de Sart-Eustache from the Criptia Group are discontinuous. They contain all the same lithology: (dark) green-grey to grey mudstone. No sign of the bedding could be found in the outcrop, not allowing to indicate the trend of the bedding. Cleavage is pervasive.

8.5.2.2. Chitinozoan results and discussion on bio- and chronostratigraphy

Five samples have been studied on their chitinozoan content (see table II.8.7). The chitinozoans are poorly preserved with abundances between 1.09 and 1.89 chitinozoans per gram of rock. We will consider every sample separate as we do not know the exact position of the samples against each other.

Sample JM 08-117 contain one specimen of *Belonechitina postrobusta* and *Conochitina* cf. *electa*. JM 08-118 contain *Conochitina* cf. *leviscapulae*. Samples JM 08-119 and JM 08-120 contain *Conochitina* cf. *iklaensis*. Sample JM 08-121 contain *Cyathochitina kuckersiana*.

Outcrop	Sample number	*Belonechitina postrobusta*	*Conochitina* cf. electa	*Conochitina* spp.	*Belonechitina* spp.	*Ancyrochitina* spp.	*Desmochitina* spp.	*Conochitina* cf. *leviscapulae*	*Angochitina* spp.	*Conochitina* cf. *iklaensis*	*Cyathochitina* spp.	*Cyathochitina kuckersiana*	*Eisenackitina* spp.	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
2	JM 08-121			9	1	1						3	1	23	38	20.06	1.89
3	JM 08-120			2						1	1			23	27	20.83	1.30
4	JM 08-119			2					4	2				9	17	20.80	0.82
4	JM 08-118							1	3					6	10	20.80	0.48
4	JM 08-117	1	1	3	1	1	1							14	22	20.23	1.09
Total		1	1	16	2	2	1	1	7	3	1	3	1	75	114	102.72	1.11

Table II.8.7. Chitinozoan results of the samples belonging to the Criptia Group, Parc de Sart-Eustache.

Belonechitina postrobusta, occurring in sample JM 08-117, occurs from the middle to upper Rhuddanian (Verniers *et al.*, 1995).

When we look at the figured specimens of Billiaert (2000) the identifications of *Belonechitina postrobusta* (in samples bb40.11 and bb40.10), *Conochitina electa* (in sample bb40.11) and *Conochitina iklaensis* (in sample bb40.11) are correct. The figured specimens of Vanmeirhaeghe (2006b), from the samples of Billiaert (2000) of *Belonechitina* cf. *postrobusta* are specimens of *Belonechitina postrobusta*. *Conochitina electa* ranges from the middle to upper Rhuddanian (Verniers, 1995) and *Conochitina iklaensis* ranges from the middle Rhuddanian up to the lower Telychian (Nestor, 2012).

The chitinozoan results are in contradiction with the observation that the Criptia Group is younger than the Génicot Formation (Vanmeirhaeghe, 2006b). The Génicot Formation has a middle to late Aeronian age. A possible explanation to this phenomenon is the reworking of the chitinozoans. Vanmeirhaeghe (2006b) indicates in the Génicot Formation outcropping in the Parc de Sart-Eustache reworking of chitinozoan specimens. Hence it is possible that the specimens identified as *Belonechitina postrobusta* and *Conochitina electa* are reworked specimens. The limited amount of samples that have been studied, 5 samples in this study and 6 samples by previous authors, together with the limited amount of field observations show that a further study of this lithological unit is needed to solve this problem.

8.6. Longues Royes Formation

The Longues Royes Formation has been created by Delcambre & Pingot (2000) and the stratotype has been defined by Verniers *et al.* (2001) along the valley of la Biesme, south of Bouffioulx. The reference section (see fig. II.8.6) is situated in the second ravine to the east of la Biesme, south of the rue de Sebastopol, approximately 2 km south of Bouffioulx, a hamlet of Châtelet.

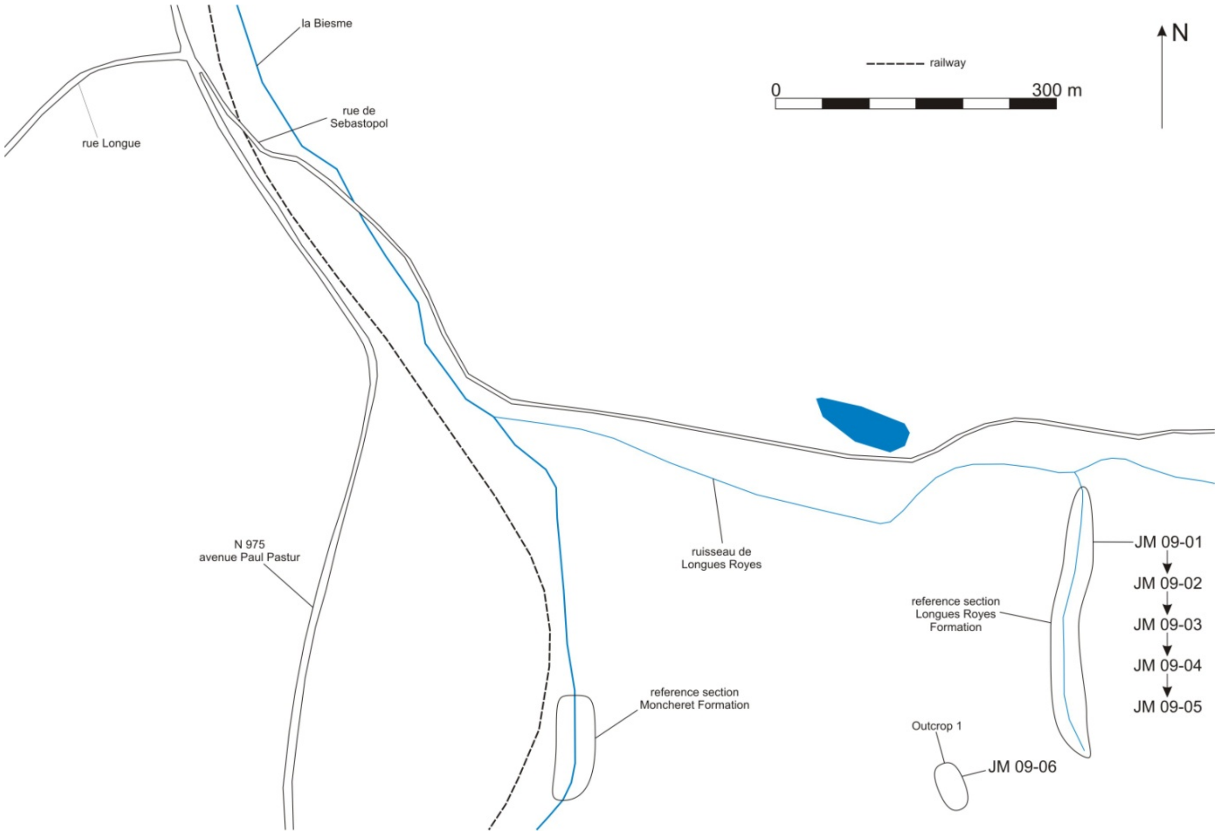


Fig. II.8.6. Map south of Bouffioulx with the location of the reference sections of the Longues Royes Formation and the Moncheret Formation and the samples. The samples JM 09-01 to JM 09-05 of the reference section are taken in southwards direction. Sample JM 09-01 is taken most northwards, sample JM 09-05 is taken most southwards in the section.

8.6.1. Earlier studies

Delcambre & Pingot (2000) describe the outcrop of the reference section as follows: it consists of green silty shale and siltstone with some darker bands. Going to the south silty and micaceous intercalations occur more frequently. The formation contains spores and acritarchs that indicate the upper Silurian (Ludlow-Pridoli) based on unpublished data of Steemans.

8.6.2. New data

8.6.2.1. Lithological results

We have studied briefly the reference section. Outcrops are present at both sides of ravine. The section consists of green to grey-green mudstone, sometimes up to coarse mudstone and is micaceous. Intercalations of dark grey mudstone occur. When moving southwards the rocks become coarser and the green colour disappears. The beds are dipping to the south.

8.6.2.2. Chitinozoan results and discussion on bio- and chronostratigraphy

Five samples have been studied on their chitinozoan content (see table II.8.8) from the reference section of the Longues Royes Formation. The chitinozoans are poorly preserved.

The abundance is always lower than 1 chitinozoan per gram of rock with one barren sample (JM 09-04). We will consider every sample separately as we do not know the exact position of the samples in relation to each other.

Formation	Sample number	*Conochitina subcyatha?*	*Conochitina* spp.	*Belonechitina* spp.	*Ancyrochitina* spp.	*Cyathochitina* sp. 1	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
Moncheret	JM 09-06		1				3	4	20.06	0.20
Longues Royes	JM 09-05		2				1	3	20.83	0.14
	JM 09-04							0	20.80	0.00
	JM 09-03					2	6	8	20.80	0.38
	JM 09-02			1	1		13	15	22.11	0.68
	JM 09-01	1	1					2	20.23	0.10
Total		1	4	1	1	2	23	32	124.83	0.26

Table II.8.8. Chitinozoan results of the samples belonging to the reference section of the Longues Royes Formation and one sample belonging to the Moncheret Formation.

The description of the chitinozoans can be short. In sample JM 09-01 *Conochitina subcyatha*? is present and in sample JM 09-03 *Cyathochitina* sp. 1.

In sample JM 09-01 the occurrence of *Conochitina subcyatha* is put under a question mark. According to Nestor (2012) it occurs in eastern Baltica in the early Homerian. If this species really occurs in the sample we can assign an age of early Homerian to sample JM 09-01.

The occurrence of *Cyathochitina* sp. 1 in sample JM 09-03 is interesting. The genus *Cyathochitina* starts to occur in the Ordovician up to the Llandovery (Paris *et al.*, 1999). This is a long range but it contradicts with earlier findings about the age of the formation who suggests a late Silurian in age. A possible reworking cannot be excluded due to also the limited amount of samples that have been studied.

No further information about the age of the Longues Royes Formation is given by the chitinozoans of the five samples of the reference section. They do not contradict with earlier findings and hence we accept the earlier age assignment of Ludlow-Pridoli.

8.7. Moncheret Formation

The Moncheret Formation has been created by Delcambre & Pingot (2000) and the stratotype has been defined by Verniers *et al.* (2001) along the valley of la Biesme, south of Bouffioulx. The reference section is situated along la Biesme, south of the rue de Sebastopol, approximately 1.8 km south of Bouffioulx (see fig. II.8.6).

8.7.1. Earlier studies

Delcambre & Pingot (2000) describe the outcrop of the reference section as follows: it consists of dark green, silty shale containing metric beds of black sandstone divided into lenticular layers or centi- to decimetric lenses of the same sandstone. The shale is often punctuated with dark patches of iron oxide or manganese oxide. The formation contains trilete spores (among which *Brochotriletes sanpetrensis*) indicating the upper Silurian (Ludlow-Pridoli) accompanied with reworked Ordovician acritarchs (Steemans, unpublished).

8.7.2. New data

8.7.2.1. Lithological results

The reference section has not been studied due to not being accessible by high water levels. An outcrop nearby belonging to the Moncheret Formation according to Delcambre & Pingot (2000) have been studied by us (see fig. II.8.6), indicated as outcrop 1. It outcrops in a small ravine of a formerly brooklet. The outcrop consists of grey to green mudstone containing beds of quite dark grey coarse mudstone to very fine sandstone (possibly lenticular) and is micaceous. The beds are dipping to the south.

8.7.2.2. Chitinozoan results and discussion on bio- and chronostratigraphy

One sample is studied, JM 09-06 (see table 8.8). It contains very poorly preserved chitinozoans with an abundance of 0.20 chitinozoans per gram of rock. Only one specimen could be determined to genus level as *Conochitina*. This genus occurs in the Ordovician and Silurian (Paris *et al.*, 1999) and hence this is also the time range that we can provide for this sample.

No further information about the age of the Moncheret Formation is given by the chitinozoans of the five samples of the reference section. They do not contradict with earlier findings and hence we accept the earlier age assignment of Ludlow-Pridoli.

8.8. Section Hautes Calenges

An additional section have been studied to cover sediments of the middle Wenlock and to obtain further information about it. This section is called Hautes Calanges.

The section is situated in the hamlet of Le Piroi belonging to municipality of the city of Namur. The outcrops are situated in the southwestern flank of the road Hautes Calenges (see fig. II.8.7).

8.8.1. Earlier studies

Manil & Ubaghs (1940) describes the section going from southeast to northwest.

1. Clayey, laminated, fine and very weathered shale. The bedding is Strike 80-90/Dip 50S. They occur over a distance of 90 meters and a minimal thickness of 68 meters. In the middle and northern part they found the following graptolites: *Cyrtograptus rigidus* (very common),

Monograptus flemingi (common), *Monograptus dubius* (rare), *Monograptus capillaceus* or *retroflexus* (a few fragments), *Monograptus lejskoviensis* (quite common), *Gothograptus* cf. *spinosus* (quite common). These graptolites indicate the *Cyrtograptus rigidus* Biozone. In the northern end of the outcrop *Monograptus flexilis* occur, a species occurring towards the top or just above the *Cyrtograptus rigidus* Biozone. Hence they assume that the layers are younging into northerly direction, and hence the layers have to be inverted.

2. Olive green shale, more compact than the previous unit without any fossils. Multiple intercalations are present of 1-1.5 m thick red shale. The layers are dipping 50-80 degrees and occur over a distance of 35 meters. These shales are younger than the previous unit. The shales are affected by little subhorizontal (slightly dipping to the south) faults. These shales belong to the Jonquoi Formation. They can be situated a little bit above the *Cyrtograptus rigidus* Biozone and below the *Neodiversograptus nilssoni* Biozone.

Martin (1969a) has studied a total of six samples on acritarchs from this outcrop. They are all barren. She assigns the outcrops to the Jonquoi Formation.

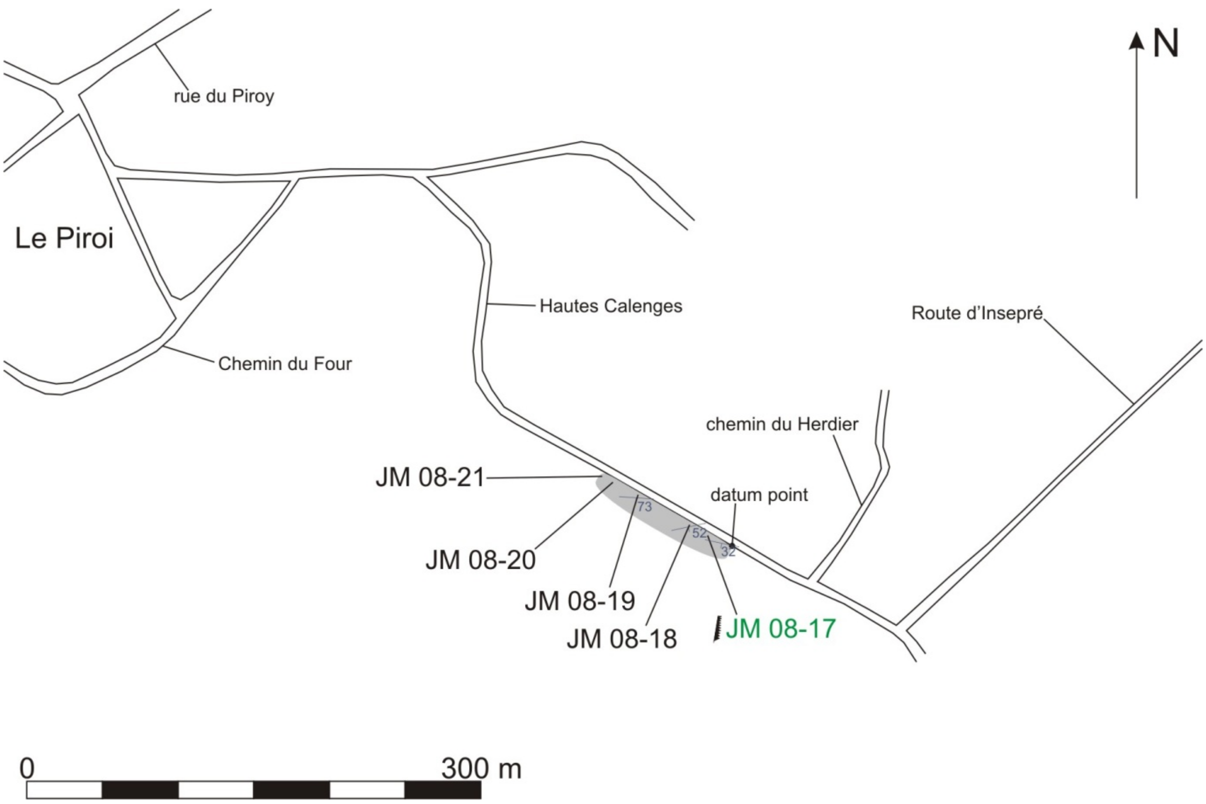


Fig. II.8.7. Map of the section Hautes Calenges.

8.8.2. New data

8.8.2.1. Lithological results

A brief study of the section have been executed. The outcrop starts at approximately 55 meters northwest of the crossroad of Hautes Calenges and chemin du Herdier (the datum point) and is approximately 100 meters long. From southeast to northwest we observe the following units:

1. Dark grey, sometimes laminated, weathered mudstone. Grey, compact mudstone (sometimes a bit coarser) with occasionally bioturbations do also occur.

2. 87.2 meters northwest from the datum point and further northwest we observe an alternation of green and red mudstone

3. 97 meters northwest from the datum point grey-green mudstone with rusty patches (up to 5 mm big) do occur. These rusty patches are possibly the result of weathering of fossils. Further northwestwards the green colour disappears together with the disappearance of the rusty patches.

8.8.2.2. Chitinozoan and graptolite results and discussion on bio- and chronostratigraphy

Four samples have been studied on their chitinozoan content (see table II.8.9). However none of them contain chitinozoans. Hence it is not possible to assign an age to the units using chitinozoans.

Sample number	Chitinozoa indet.	Total chitinozoans	Sample weight (g)	Chitinozoans / g rock
JM 08-21		0	20.80	0.00
JM 08-20		0	20.80	0.00
JM 08-19		0	22.11	0.00
JM 08-18		0	20.23	0.00
Total	0	0	83.94	0.00

Table II.8.9. Chitinozoan results of the section Hautes Calenges.

One graptolite have been found by us (sample JM 08-17) in unit 1. The graptolite is studied and identified by Prof. Dr. Petr Storch (Institute of Geology AS CR, Prague, Czech Republic). Unfortunately the graptolite cannot be identified but it is possibly a cyrtograptid metacladium.

Following the graptolite determinations of Manil & Ubaghs (1940) we can say that unit 1 belongs to the *Cyrtograptus rigidus* Biozone of the middle Wenlock. The age of the rocks of unit 2 and 3 is unknown. We cannot confirm or disconfirm that the rocks become younger going northwestwards.

8.9. Systematical discussion and plates

8.9.1. Systematical discussion

Systematics of the chitinozoans

Incertae sedis group Chitinozoa Eisenack, 1931

Order Prosomatifera Eisenack, 1972

Family Conochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Conochitinae Paris, 1981

Genus *Conochitina* Eisenack, 1931 emend. Paris *et al.*, 1999

Conochitina claviformis?

Plate II.8.2., specimen 16

Material: 1 specimen from JM 08-15, Fosses-la-Ville.

Dimensions: L: ≥183 µm (n=1); Dp: 62 µm (n=1).

Description: we refer for the description to Eisenack, 1931 and additional description to Nestor, 1994.

Discussion: The specimen is deformed hence the form of the vesicle is unclear. We prefer the use of open nomenclature.

Conochitina cf. *electa*

Plate II.8.2., specimen 8

Material: 1 specimen from JM 08-117, Parc de Sart-Eustache, Sart-Eustache.

Dimensions: L: >146 µm (n=1); Dp: 65 µm (n=1).

Description: we refer for the description to Nestor, 1980b & 1994.

Discussion: The chamber of the specimen cannot be 1/2 to 1/3 of the total vesicle length as described for real *Conochitina electa*, even with this specimen where a part of the neck is broken off.

Conochitina cf. *iklaensis*

Plate II.8.2., specimen 10

Material: 2 specimens from JM 08-119, 1 specimen from JM 08-120, Parc de Sart-Eustache, Sart-Eustache.

Dimensions: L: >190->250 µm (n=3); Dp: 82-90 µm (n=2).

Description: we refer for the description to Nestor, 1980a & 1994.

Discussion: The specimens are not completely preserved, hence the use of open nomenclature.

Conochitina cf. *leviscapulae*

Material: 1 specimen from JM 08-118, Parc de Sart-Eustache, Sart-Eustache.

Dimensions: L: ≥171 µm (n=1); Dp: 101 µm (n=1).

Description: we refer for the description to Mullins & Loydell, 2001.

Discussion: The specimen is insufficiently preserved to allow a definite identification.

Conochitina cf. *proboscifera*

Plate II.8.2., specimen 15

Material: 1 specimen from JM 07-22, Naninne.

Dimensions: L: >345 µm (n=1); Dp: 68 µm (n=1).

Description: The species is subcylindrical with slightly convex flanks. The base is flat and the basal margin is rounded. No mucron is visible (it can be hidden). The vesicle wall is smooth and thick.

Discussion: Only 1 specimen has been recovered. No mucron can be seen although on *Conochitina proboscifera* (Eisenack, 1937) it is always clearly present.

Conochitina subcyatha?

Plate II.8.3., specimen 10

Material: 1 specimen from JM 09-01, Bouffioulx.

Dimensions: L: 139 µm (n=1); Dp: 60 µm (n=1); Dc: 40 µm (n=1).

Description: we refer for the description to Nestor, 1982a & 1994.

Discussion: The specimen is smaller in comparison with the description of *Conochitina subcyatha* (Nestor, 1982a). No clear flexure and shoulders are developed.

Subfamily Belonechitininae Paris, 1981

Genus *Belonechitina* Jansonius, 1964

Belonechitina postrobusta

Material: 1 specimen from JM 08-117, Sart-Eustache.

Dimensions: L: ≥280 µm (n=1).

Description: we refer for the description to Nestor, 1980a & 1994.

Discussion: The specimen fits in the description of Nestor, 1980a & 1994. The specimens illustrated by Vanmeirhaeghe (2006b) from the Criptia Group (plate 29, fig. 3-5 + 10), Parc de Sart-Eustache, Sart-Eustache and determined as *Belonechitina* cf. *postrobusta,* are according to us *Belonechitina postrobusta*.

Family Lagenochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Cyathochitininae Paris, 1981

Genus *Cyathochitina* Eisenack, 1955b

Cyathochitina cf. *calix*

Plate II.8.1., specimens 8, 9

Material: 4 specimens from JM 08-02, Dave.

Dimensions: L: >180->275 (n=4); Dp: 95-115-136 µm (n=3); Dc: 46-60 µm (n=2).

Description: we refer for the description to Eisenack, 1931.

Discussion: The preservation of the specimens is too poor to be identified as typical specimens of the species.

Cyathochitina sp. 1

Plate II.8.3., specimens 11, 12

Material: 2 specimens from JM 09-03, Bouffioulx.

Dimensions: L: >343-≥440 µm (n=2); Dp: 137-155 µm (n=2); Dc: 69 µm (n=1).

Description: The species has elongated, slightly swollen flanks going into a subcylindrical neck slightly widening to the aperture. The flexure is present, shoulders are absent. The width of the vesicle is greatest at the base where a medium-sized carina is present. The vesicle surface is granulate to wrinkled.

Discussion: The species resembles *Cyathochitina calix* (Eisenack, 1931). But it is distinguished by the length of the carina: our species has a longer carina where *Cyathochitina calix* only has a short carina.

Genus *Sagenachitina* Jenkins, 1970

Sagenachitina sp. 1

Plate II.8.1., specimen 1

Material: 1 specimen from JM 08-02, Dave

Dimensions: L: ≥125 µm (n=1); Dp: 100 µm (n=1); Dc: 41 µm (n=1).

Description: The species has a convex base. A perforated carina is present on the rounded basal margin. The carina becomes perforated quite quickly starting from the chitinozoan vesicle. The flanks of the chamber are convex going into a subcylindrical neck, very slightly widening to the aperture. The flexure is present, shoulders are absent. The vesicle wall is smooth. Vertical ribbing is present close to the transition of the chamber and the neck.

Discussion: It is not clear if the neck is broken or not. When the neck is not broken, the length of the neck is approximately 1/3 of the total length of the species. A characteristic element of the species is the small size.

Subfamily Ancyrochitininae Paris, 1981

Genus *Ancyrochitina* Eisenack, 1955a

Ancyrochitina cf. *desmea*

Plate II.8.3., specimen 7

Material: 1 specimen from JM 09-10, Fosses-la-Ville.

Dimensions: L: ≥130 µm (n=1); Dp: >71 µm (n=1); Dc: 38 µm (n=1).

Description: we refer for the description to Eisenack, 1964 and additional description to Laufeld, 1974.

Discussion: The specimen is insufficiently preserved to allow a certain determination. A part of the neck is possibly broken off because the prosome is almost completely visible.

Order Operculatifera Eisenack, 1931

Family Desmochitinidae Eisenack, 1931 emend. Paris, 1981

Subfamily Eisenackitininae Paris, 1981

Genus *Eisenackitina* Jansonius, 1964 restrict. Paris, 1981

Eisenackitina cf. *inanulifera*

Plate II.8.3., specimen 1

Material: 1 specimen from JM 08-15, Fosses-la-Ville.

Dimensions: L: 149 µm (n=1); Dp: 97 µm (n=1); Dc: 52 µm (n=1).

Description: we refer for the description to Nestor, 2005.

Discussion: The base of the specimen is not visible and is broken off. Hence we cannot distinguish between *Eisenackitina anulifera* (Verniers, 1999) and *Eisenackitina inanulifera* (Nestor, 2005) although no ring-like thickenings are present as is typical for *Eisenackitina anulifera*. Only one specimen has been recovered, hence we prefer the use of an open nomenclature.

Eisenackitina sp. 1

Plate II.8.2., specimens 5, 6

Material: 2 specimens from JM 08-03, Dave.

Dimensions: L: 97-100 µm; Dp: 77-78 µm.

Description: The species has an ovoid body and is sealed by an operculum. The vesicle wall is ornamented with very densely placed spines forming a reticulate cover over the vesicle.

Discussion: The species can be compared with *Desmochitina erinacea* (Eisenack, 1931). But the latter has never such a complex ornamentation. Hence the use of the genus *Eisenackitina*.

Subfamily Orbichitininae Achab, Asselin & Soufiane, 1993

Genus *Salopochitina* Swire, 1990 emend. Paris *et al*., 1999

Salopochitina? sp. 1

Plate II.8.1., specimens 2-7

Material: 11 specimens from JM 08-02, Dave

Dimensions: L: 105-119-153 µm (n=6); Dp: 55-73-105 µm (n=9); Dc: 25-32-38 µm (n=5).

Description: The species has an ovoid chamber going into a neck tapering to the aperture. The basal margin is broadly rounded and bears a carina-like rim. On this rim generally four sheathing and long processes are present, in seldom cases branching one more time.

Discussion: The species resembles well the *Salopochitina* species of Vanmeirhaeghe, 2006 & 2007a (described as *Salopochitina* sp. A). Our species differ from it by the slightly longer neck and generally four processes. We prefer the use of a question mark following the genus name as *Salopochitina* strictly does not have a neck. Except for the presence of the neck, the specimens possess all the characteristics of a typical *Salopochitina*. *Salopochitina* species are only known to occur from the Wenlock and Ludlow (Paris *et al*., 1999). Except for Vanmeirhaeghe (2006 & 2007a) and Paris *et al* (2007) who found *Salopochitina* species in Middle Ordovician strata. Their specimens possess also a neck and these authors also question the assignment to this genus due to this criterion. Although they do not use a question mark.

8.9.2. Plates of the chitinozoans

Plate II.8.1. Chitinozoans from different sections. The locality is indicated below on every specimen.

1. *Sagenachitina* sp. 1. L: 125 µm; Dp: 100 µm; Dc: 41 µm. Dave. JM 08-02.

2. *Salopochitina*? sp. 1. L: 128 µm; Dp: 68 µm; Dc: 33 µm. Dave. JM 08-02.

3. *Salopochitina*? sp. 1. L: 153 µm; Dp: 85 µm; Dc: 38 µm. Dave. JM 08-02.

4. *Salopochitina*? sp. 1. L: ≥118 µm; Dp: 80 µm; Dc: ≤32 µm. Dave. JM 08-02.

5. *Salopochitina*? sp. 1. L: 105 µm; Dp: 69 µm; Dc: 33 µm. Dave. JM 08-02.

6. *Salopochitina*? sp. 1. L: 105 µm; Dp: 60 µm; Dc: 25 µm. Dave. JM 08-02.

7. *Salopochitina*? sp. L: 195 µm; Dp: 100 µm; Dc: 50 µm. Dave. JM 08-02.

8. *Cyathochitina* cf. *calix*. L: >240 µm; Dp: 113 µm; Dc: 60 µm. Dave. JM 08-02.

9. *Cyathochitina* cf. *calix*. L: >180 µm; Dp: 95 µm; Dc: ≤46 µm. Dave. JM 08-02.

10. *Euconochitina vulgaris*. L: 107 µm; Dp: 69 µm; Dc: 40 µm. Dave. JM 08-03.

11. *Euconochitina vulgaris*. L: 120 µm; Dp: 83 µm; Dc: 48 µm. Dave. JM 08-03.

12. *Euconochitina vulgaris*. L: 137 µm; Dp: 79 µm; Dc: 45 µm. Dave. JM 08-03.

13. *Euconochitina vulgaris*. L: 118 µm; Dp: 77 µm; Dc: 45 µm. Dave. JM 08-03.

14. *Euconochitina vulgaris*. L: 109 µm; Dp: 72 µm; Dc: 41 µm. Dave. JM 08-03.

15. *Euconochitina vulgaris*. L: 149 µm; Dp: 86 µm; Dc: 48 µm. Dave. JM 08-03.

16. *Siphonochitina* sp. L: 155 µm; Dp: 60 µm; Dc: ≤33 µm. Dave. JM 08-03.

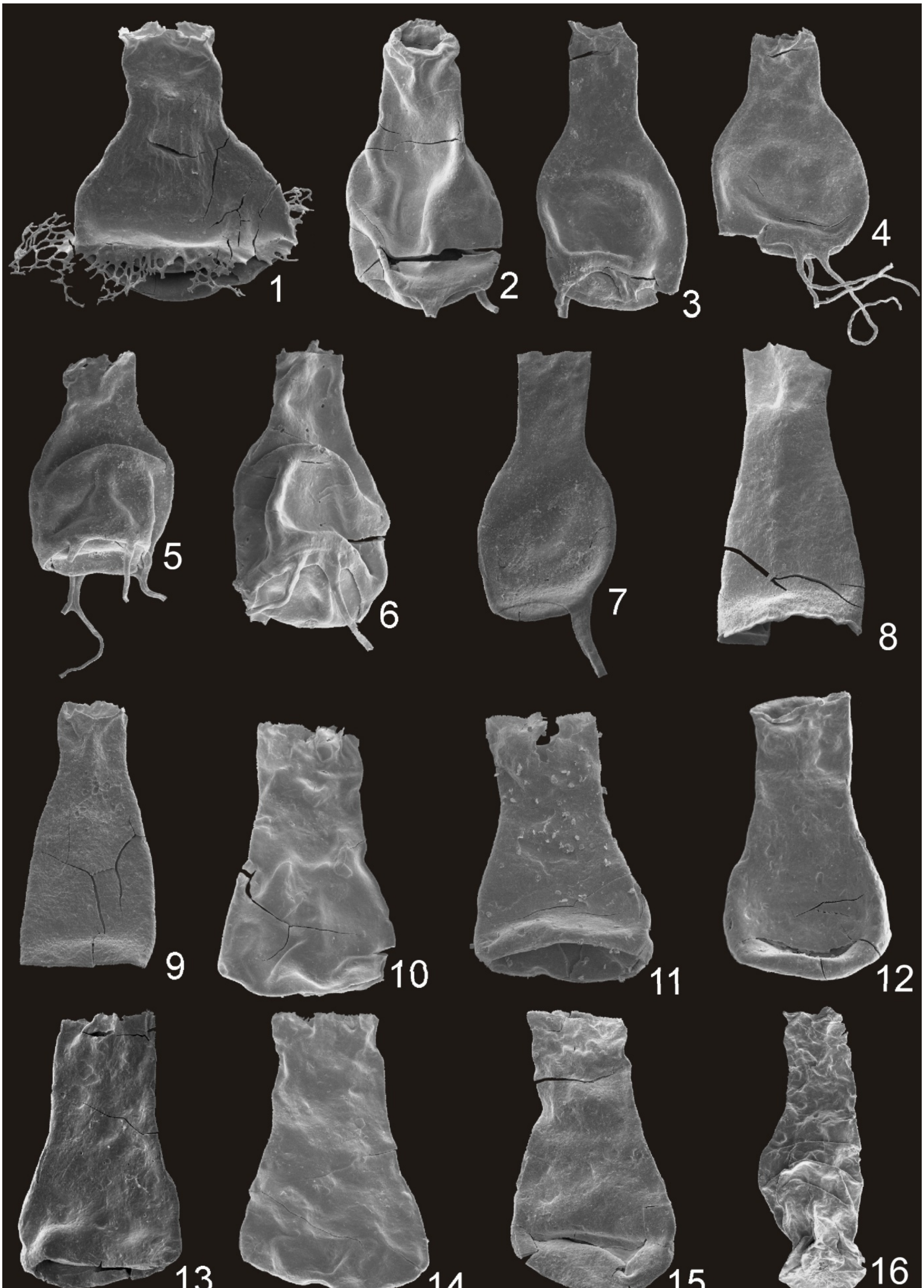


Plate II.8.1.

Plate II.8.2. Chitinozoans from different sections. The locality is indicated below on every specimen.

1. *Conochitina chydaea*. L: >151 µm; Dp: 60 µm; Dc: ≤45 µm. Dave. JM 08-03.

2. *Conochitina chydaea*. L: 170 µm; Dp: 69 µm; Dc: 44 µm. Dave. JM 08-03.

3. *Conochitina chydaea*. L: 173 µm; Dp: 68 µm; Dc: 46 µm. Dave. JM 08-03.

4. *Conochitina chydaea*. L: 140 µm; Dp: 66 µm; Dc: 41 µm. Dave. JM 08-03.

5. *Eisenackitina* sp. 1. L: 100 µm; Dp: 78 µm. Dave. JM 08-03.

6. *Eisenackitina* sp. 1. L: 97 µm; Dp: 77 µm. Dave. JM 08-03.

7. *Belonechitina postrobusta*. L: 280 µm; Dp: ±80 µm; Dc: 73 µm. Sart-Eustache. JM 08-117.

8. *Conochitina* cf. *electa*. L: >146 µm; Dp: 65 µm; Dc: ≤40 µm. Sart-Eustache. JM 08-117.

9. *Angochitina* sp. L: ≥133 µm; Dp: 66 µm; Dc: 33 µm. Sart-Eustache. JM 08-118.

10. *Conochitina* cf. *iklaensis*. L: >190 µm; Dp: ≥58 µm. Sart-Eustache. JM 08-119.

11. *Conochitina* sp. L: >180 µm; Dp: 54 µm; Dc: ≤40 µm. Sart-Eustache. JM 08-119.

12. *Angochitina* sp. L: 140 µm; Dp: 60 µm; Dc: 33 µm. Sart-Eustache. JM 08-119.

13. *Cyathochitina kuckersiana*. L: >250 µm; Dp: 130 µm; Dc: 62 µm. Sart-Eustache. JM 08-121.

14. *Cyathochitina kuckersiana*. L: >291 µm; Dp: 145 µm; Dc: 59 µm. Sart-Eustache. JM 08-121.

15. *Conochitina* cf. *proboscifera*. L: >345 µm; Dp: 68 µm. Naninne. JM 07-22.

16. *Conochitina claviformis*?. L: 183 µm; Dp: 62 µm; Dc: 29 µm. Fosses-la-Ville. JM 08-15.

Plate II.8.2.

Plate II.8.3. Chitinozoans from different sections. The locality is indicated below on every specimen.

1. *Eisenackitina* cf. *inanulifera*. L: 149 µm; Dp: 97 µm; Dc: 52 µm. Fosses-la-Ville. JM 08-15.

2. *Angochitina* sp. L: 149 µm; Dp: 55 µm; Dc: 31 µm. Fosses-la-Ville. JM 08-15.

3. *Angochitina* sp. L: ≥157 µm; Dp: 74 µm; Dc: 32 µm. Fosses-la-Ville. JM 08-15.

4. *Angochitina* sp. L: 167 µm; Dp: 70 µm; Dc: 30 µm. Fosses-la-Ville. JM 08-15.

5. *Desmochitina* sp. L: 110 µm; Dp: 65 µm; Dc: 37 µm. Fosses-la-Ville. JM 08-16.

6. *Eisenackitina* sp. L: 92 µm; Dp: 73 µm; Dc: 45 µm. Fosses-la-Ville. JM 08-16.

7. *Ancyrochitina* cf. *desmea*. L: 130 µm; Dp: >71 µm; Dc: 38 µm. Fosses-la-Ville. JM 09-10.

8. *Ancyrochitina* sp. L: 126 µm; Dp: 69 µm; Dc: 25 µm. Fosses-la-Ville. JM 09-10.

9. *Ancyrochitina* sp. L: >120 µm; Dp: 71 µm; Dc: 25 µm. Fosses-la-Ville. JM 09-10.

10. *Conochitina subcyatha*?. L: 139 µm; Dp: 60 µm; Dc: 40 µm. Bouffioulx. JM 09-01.

11. *Cyathochitina* sp. 1. L: 343 µm; Dp: >155 µm; Dc: 69 µm. Bouffioulx. JM 09-03.

12. *Cyathochitina* sp. 1. L: 440 µm; Dp: 137 µm; Dc: 50 µm. Bouffioulx. JM 09-03.

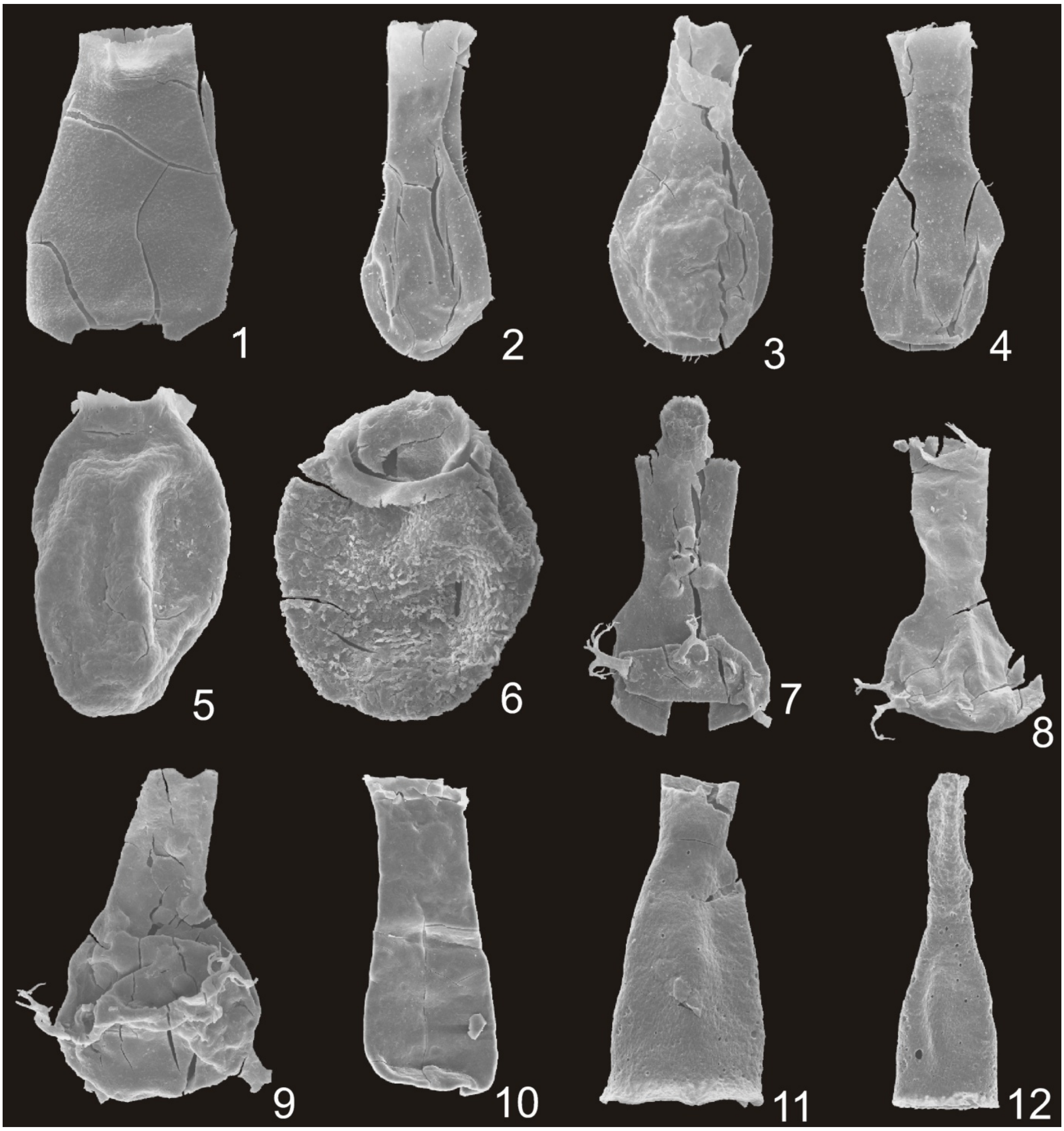


Plate II.8.3.

PART III – Discussion

1. New insights in the lithostratigraphical units of the Upper Ordovician to Silurian of the Condroz Inlier and the Brabant Massif

see also fig. III.1.1

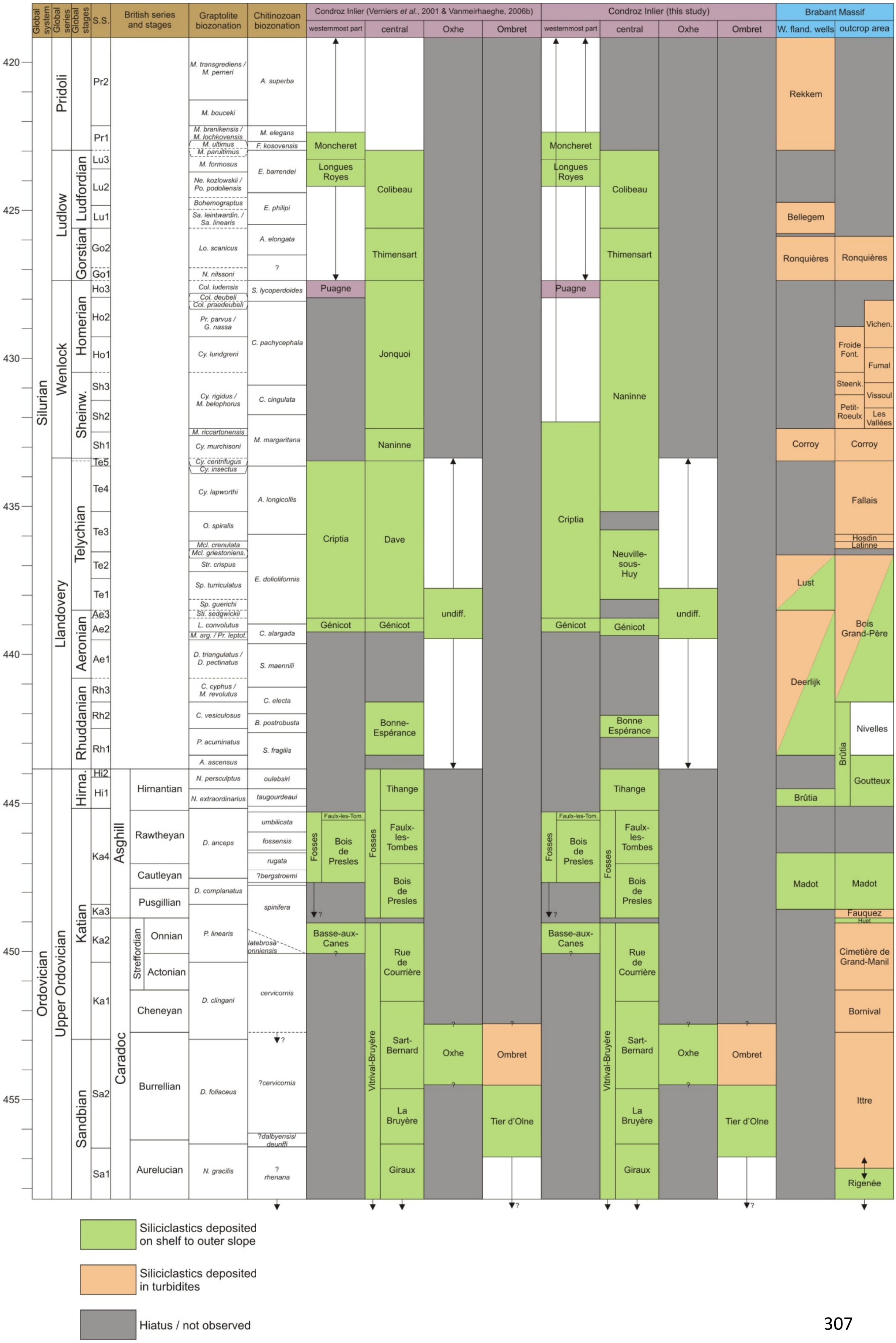
The lithostratigraphical units of the Upper Ordovician and a part of the Llandovery of the Condroz Inlier have been studied, reappraised, and mostly redefined by Vanmeirhaeghe (2006b). We accept his redefinitions of the lithostratigraphical units of the Upper Ordovician of the Condroz Inlier without need for additions, except for two modifications.

Vanmeirhaeghe (2006b) defined the Tihange Member as the uppermost part of the Fosses Formation. We prefer to raise the rank of the member to the level of formation as the lithology and sedimentology is too much different from the Fosses Formation. Hence the Fosses Formation contains only two members: the Bois de Presles Member and the Faulx-les-Tombes Member. The covering unit is the Tihange Formation. For the first time the age of the formation has been assigned without question to the Hirnantian and for the first time the Hirnantian is proven to exist in the Condroz Inlier.

The graptolites in the Bonne Espérance Formation indicate the upper (?) part of the *acuminatus* Biozone to the *atavus* Biozone refining the biostratigraphical information of Vanmeirhaeghe (2006b). He uses the identifications of Michot (1932a, 1934, 1954) assigning it to the *acuminatus* and *vesiculosus* Biozones. The *atavus* Biozone corresponds to the lower part of the *vesiculosus* Biozone. A spelling remark is done on the Bonne Espérance Formation. Vanmeirhaeghe (2006b) uses a hyphen between the words Bonne and Espérance for defining the Bonne Espérance Formation. This is probably due to the fact that he assumed that one is present in the name of the rue Bonne Espérance at Tihange. No hyphen is present in the name of the street and we use the name of Bonne Espérance Formation instead of Bonne-Espérance Formation.

A more detailed description of the Tihange Formation and the Bonne Espérance Formation can be found in chapter I.1.

The lower part of the Brûtia Formation, the Goutteux Member, was before our study not well known. The part of the Goutteux Member outcropping in Hennuyères consists of green-grey mudstone with dark grey bioturbations present as fucoids and occasionally small rusty patches. Dark grey mudstone, intermingled with the green-grey mudstone, also occur. Previous studies correlated this member with the Hirnantian without much proof. In the Orneau valley, outcrop area, *Belonechitina* cf. *gamachiana* is found indicating possibly the Hirnantian (Samuelsson & Verniers, 1999, 2000). In a borehole in West Flandres, Harelbeke, a similar facies was recovered and chitinozoans indicate the lower or lower upper Hirnantian with the presence of *Spinachitina taugourdeaui* (Van Grootel, 1995 & Vanmeirhaeghe, 2006b). It proves for the first time the presence of Hirnantian sediments, more specifically the lower or lower upper Hirnantian, in the Brabant Massif. This facies is recently correlated by Herbosch & Verniers (2014) to the Goutteux Member. In Hennuyères chitinozoans indicate the upper Hirnantian. For the first time the upper Hirnantian is proven to exist in the outcrop area.



Global system
Global series
Global stages
S.S.
British series and stages
Graptolite biozonation
Chitinozoan biozonation
Condroz Inlier (Verniers et al., 2001 & Vanmeirhaeghe, 2006b)
westernmost part
central
Oxhe
Ombret
Condroz Inlier (this study)
Brabant Massif
W. fland. wells
outcrop area
Silurian
Ordovician
Pridoli
Ludlow
Wenlock
Llandovery
Upper Ordovician
Ludfordian
Gorstian
Homerian
Sheinw.
Telychian
Aeronian
Rhuddanian
Hirna.
Katian
Sandbian
Ashgill
Caradoc
Hirnantian
Rawtheyan
Cautleyan
Pusgillian
Streffordian
Onnian
Actonian
Cheneyan
Burrellian
Aurelucian
Moncheret
Longues Royes
Colibeau
Thimensart
Puagne
Jonquoi
Naninne
Criptia
Dave
Génicot
undiff.
Neuville-sous-Huy
Bonne-Espérance
Tihange
Fosses
Bois de Presles
Faulx-les-Tombes
Basse-aux-Canes
Vitrival-Bruyère
Rue de Courrière
Sart-Bernard
La Bruyère
Giraux
Ombret
Tier d'Olne
Rekkem
Bellegem
Ronquières
Corroy
Fallais
Lust
Deerlijk
Brûtia
Madot
Bois Grand-Père
Nivelles
Goutteux
Fauquez
Cimetière de Grand-Manil
Bornival
Ittre
Rigenée
Siliciclastics deposited on shelf to outer slope
Siliciclastics deposited in turbidites
Hiatus / not observed

Fig. III.1.1. Previous page. Overview of the litho-, bio- and chronostratigraphy of the Condroz Inlier as the result of our study and comparison with the previous stratigraphy. The column of the Brabant Massif has changed on one position: the lower boundary of the Brûtia Formation. The chronostratigraphy, numerical ages and graptolite biozonation are from Gradstein *et al.* (2012). The stage slices for the Upper Ordovician are from Bergström *et al.* (2009), these for the Silurian are from Cramer *et al.* (2011a), the chitinozoan biozonation of Avalonia for the Upper Ordovician is from Vandenbroucke (2008b), the Silurian global chitinozoan biozonation is from Verniers *et al.* (1995).

The Génicot Formation has been thoroughly studied by Vanmeirhaeghe (2006b; for a description we refer to chapter I.4.3.1.1.). The lithostratigraphical unit is well known and studied in the western part of the Condroz Inlier, but is not known to occur in the eastern part of the Condroz Inlier. Unit 1 and unit 2 of the section Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville are attributed to the Génicot Formation. According to Vanmeirhaeghe (2006b) the lower part of the Génicot Formation consists of "medium to dark grey, micaceous siltstones containing at most levels densely spaced millimetric, sometimes patchy rusty laminae". This description fits our description for unit 1 and unit 2 and we place these two units in the Génicot Formation. Hence for the first time the Génicot Formation is known to also occur in the eastern part of the Condroz Inlier. The presence of *Spinachitina maenilli*, *Conochitina alargada* and *Conochitina malleus* in unit 1 indicate a range of the upper part of the middle Aeronian to the lower part of the upper Aeronian.

The sediments of the Dave Formation, middle-upper Aeronian to Telychian, at Dave are different in comparison with these at Neuville-sous-Huy. The samples at Dave, supposedly from the Dave Formation according to Michot (1932b, 1934), contain chitinozoans indicative for the upper part of the Lower Ordovician to the Middle Ordovician and certainly not Llandovery. Martin (1969a) noted this already from another outcrop at Dave supposedly belonging to the Dave Formation (see above chapter II.8.1). These two arguments argue to change the definition of the Dave Formation (see below). A new formation name is created for the sediments at Neuville-sous-Huy of the lower to middle Telychian: the Neuville-sous-Huy Formation. A description of the new formation is found below. It correspond to the rocks in outcrop 1-4 of the section of Neuville-sous-Huy, Parc de la Neuville; unit 1, 2 and 4 of Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville; unit 3-8 of Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville. The *crenulata* graptolite Biozone have been described by previous authors (Michot, 1932a, 1934; Vandevelde, 1976; Maes, 1976; Maes *et al.*, 1978) corresponding to previously the middle-upper Telychian. This Biozone was later on divided into four Biozones with the *crenulata* Biozone the lowest corresponding to the middle Telychian. Our results indicate that only graptolites are found belonging to the *crenulata* Biozone of the middle Telychian. Interesting to note is that Maes *et al.* (1978) interpreted the presence of three volcaniclastic layers in the lower Wenlock and this was followed by later authors. These volcaniclastic layers correspond to V7, V8 and V9 of the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville. We interpret these volcaniclastic layers as

belonging to the Neuville-sous-Huy Formation and hence no volcaniclastic layers are no more present in the lower Wenlock of the Condroz Inlier.
The usage of the name Dave Formation is however not abandoned but the definition is slightly changed. The outcrops at Dave, described by Michot (1932b) as "schistes de Dave", correspond to the rocks present in the Ruisseau de Chevreuils, also in Dave, where the Chevreuils Formation is defined (Vanmeirhaeghe, 2006b). We prefer to abandon the name of the Chevreuils Formation and change it to the name of Dave Formation.

The Wenlock of the Condroz Inlier is characterized by two types of sediments according to Michot (1934, 1954): slightly calcareous, slightly sandy, laminated shale with some sandstone levels belonging to the *murchisoni* and the *riccartonensis* Biozones; green shale and sandy shale belonging to the *rigidus* to *ludensis* Biozones although no graptolites are found in this lithology. This view is modified by the description of Manil & Ubaghs (1940) of the section Hautes Calenges (see chapter II.8.8). They found in laminated shale graptolites belonging to the *rigidus* Biozone. Furthermore Rombouts (1976) and Maes *et al.* (1978) discovered in the section of Parc de la Neuville the *rigidus-lundgreni* Biozones in grey blue and green finely laminated shale.
We interpret the upper Telychian and the Wenlock of the Condroz Inlier as almost dominated by only one facies: dark grey, finely laminated mudstone known as laminated hemipelagites. For the first time this lithology is described in the Condroz Inlier.
In the section of Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville, after a fault contact, dark grey to dark green grey mudstone occurs (corresponding to unit 9 of the section). Towards higher levels the frequency of the laminations becomes higher until at the top almost only a finely laminated mudstone occurs. The green colour disappears also towards higher levels. *Conochitina acuminata*, present in unit 9, occurs starting in the *Cyrtograptus lapworthi* Biozone (upper Telychian; Nestor, 2012). Approximately 4.3 meters higher graptolites occur indicating the *insectus* to lower *centrifugus* Biozone. In the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville dark grey, finely laminated mudstone occur (unit 3 of the section) of the *insectus*? to *centrifugus* Biozone.
In the section of Neuville-sous-Huy, new road 300 m west of Parc de la Neuville in unit 1 *Sphaerochitina lycoperdoides* occurs indicating the upper Homerian to possibly the lower Gorstian (Verniers *et al.*, 1995; Nestor, 2012; Grahn, 1996) in dark grey, finely laminated mudstone indicating that this facies is still present in the upper Homerian. The facies of the *nilsonni* Biozone is different (see below), hence it is likely that it can be situated in the upper Homerian.
Other sections containing sediments of the *murchisoni* Biozone up to the uppermost part of the Wenlock contain almost only one lithology: dark grey, finely laminated mudstone sometimes containing centimetric intercalations of dark grey, compact mudstone. The dark grey, finely laminated mudstone are laminated hemipelagites. But other lithologies are also present occurring in between the laminated hemipelagites. In the Parc de la Neuville along the southern pond limestone nodules are present in this lithology and is placed in the *Cyrtograptus rigidus* Biozone of the upper Sheinwoodian. Compact layers of mudstone also occur in the Wenlock but these cannot be situated exactly in the chronostratigraphy. In the section of Hautes Calenges green, grey-green and red mudstone occur above beds of the

Cyrtograptus rigidus Biozone (Manil & Ubaghs, 1940). In the section of the Parc de la Neuville along the southern pond in unit c green-grey to grey, sometimes laminated, compact mudstone occurs. This unit occurs probably above unit b belonging to the *Cyrtograptus rigidus* Biozone. Michot (1934, 1954) describes olive green shale in the region of Fosses-la-Ville that should be located between the *riccartonensis* Biozone and the *nilssoni* Biozone but an exact stratigraphical position of these shale is not known.
We prefer to abandon the name of the Jonquoi Formation as we do not see a difference in the lithology of the upper Telychian to the upper Wenlock. We retain the name of the Naninne Formation and use it for sediments of the upper Telychian to Wenlock mainly composed of dark grey, finely laminated mudstone. A volcaniclastic layer occurs in the section of Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville (indicated as Vγ) in the lowermost part of the formation. Five pale clay levels of volcaniclastic origin are observed in the section of Neuville-sous-Huy, new road 300 m west of Parc de la Neuville in sediments of the *rigidus-lundgreni* Biozones.

A change in the sedimentation takes place starting in the Ludlow. At Fosses-la-Ville grey, laminated mudstone, sometimes slightly coarser, occur belonging to the *nilssoni* Biozone. In a sunken small road at Fosses-la-Ville the same lithology exists with brown laminae. Graptolites indicative for the lower part of *chimaera-scanicus* Biozone are found. The same Biozone have been found along the southern pond of Parc de la Neuville in olive green, grey-green to brown-green compact mudstone with beds of dark grey laminated mudstone and brown to rusty laminae corresponding to the same lithology. Sediments of the middle Gorstian to the lower part of the Upper Gorstian are encountered there. The sediments of the Parc de la Neuville contain grey-green, olive green, green-grey to grey mudstone, compact or sometimes laminated. We group these sediments in the Thimensart Formation of the Gorstian.

In Neuville-sous-Huy, section ravine 700 m east of Parc de la Neuville olive green mudstone occur (unit 6 of the section) ranging from the middle Gorstian to the lower Ludfordian based on the occurrence of *Angochitina echinata* and *Belonechitina latifrons*. The outcrop is small and it is not possible to assign a formation to this outcrop.

Only one outcrop is known of the Colibeau Formation (near Naninne, at the locality of "Colibeau", railway Namur-Arlon) and the outcrop is small. Hence no description of this outcrop was possible. Hence we take the description of Malaise (1913), Maillieux (1930) and Martin (1969a). The Colibeau Formation consists of dark grey to brownish black, coarse-grained mudstone containing a lot of mica with rare intercalations of clayey sandstone. It belongs to the upper Ludlow based on the occurrence of *Spirifer elevatus*, *Plethoryncha percostata* and *Stropheodonta simulans*. Only one specimen was found of each species. The thickness is estimated by Michot (1954, 1957) at 650 meters.

In the Puagne Inlier the Criptia Group occurs stratigraphically above the Génicot Formation. The outcrops of the Parc de Sart-Eustache of this lithostratigraphical unit contains (dark) green-grey to grey mudstone. It should be younger than the Génicot Formation where graptolites occur of the *convolutus* Biozone, and brachiopods indicating the Aeronian.

Vanmeirhaeghe (2006b) correlates tentatively (at least a part of) the unit with the Dave Formation that is now the Neuville-sous-Huy Formation. *Belonechitina postrobusta* have been found confirming the observation of Billiaert (2000) and Vanmeirhaeghe (2006b; as *Belonechitina* cf. *postrobusta*) of this species. Billiaert (2000) found next to this species also *Conochitina electa* and *Conochitina iklaensis*. These species are in contradiction with the observation that the Criptia Group is younger than the Génicot Formation. A possible explanation for this phenomenon is the process of reworking but further study is necessary to solve this problem. The Criptia Group is only known in the Puagne Inlier. This tectonic wedge contains sediments that were deposited significantly further in comparison with these of the central Condroz Inlier. They were brought together by Variscan tectonics. Hence the lithostratigraphical units of the Puagne Inlier should be handled independently. This has as consequence that we cannot correlate the Criptia Group with a lithostratigraphical unit present in the central Condroz Inlier. We do not follow Vanmeirhaeghe (2006b) to correlate the Criptia Group with the newly defined Neuville-sous-Huy Formation as we do not have any arguments for that. We propose a late Llandovery to tentatively Pridoli age for the Criptia Group.

In the westernmost part of the Condroz Inlier the Longues Royes Formation and the covering Moncheret Formation occurs.

The Longues Royes Formation contains green to grey-green mudstone up to coarse mudstone, micaceous with intercalations of dark grey mudstone. Unfortunately the chitinozoans in our study do not give us more information than the Ludlow-Pridoli age as previously indicated.

The Moncheret Formation contains grey to dark grey and dark green mudstone containing beds of dark grey coarse mudstone to very fine sandstone (possibly lenticular). The chitinozoans in our study do not provide a more detailed age than previously attributed of Ludlow-Pridoli.

1.1. Definitions of the lithostratigraphical units of a part of the Upper Ordovician and Silurian of the Condroz Inlier

<u>Tihange Formation</u>

<u>Name and stratotype:</u> The Tihange Formation was first described and defined by Vanmeirhaeghe (2006b) as the Tihange Member, the uppermost member of the Fosses Formation. Its stratotype is assigned by Vanmeirhaeghe (2006b) in the section rue Bonne Espérance from 94 m to 70 m north of the southern intersection of rue Rouge Lion and rue Bonne Espérance, and also in the section rue Rouge Lion, from 75.3 to 94.4 m south of the northern intersection of the rue Rouge Lion and the rue Bonne Espérance. We define for the Tihange Formation a composite-stratotype in the section rue Bonne Espérance and the section rue Rouge Lion: from 94 m to 70 m north of the southern intersection of the rue Rouge Lion and the rue Bonne Espérance; from 74.4 m to 95.2 m south of the northern the intersection of the rue Rouge Lion and the rue Bonne Espérance.

Area and previous records: The Tihange Formation is, until now, only known from sections of Tihange, eastern part central Condroz Inlier. The outcrops have been studied previously by Malaise (1907), Michot (1932a, 1934, 1954), Martin (1969a) and Vanmeirhaeghe (2006b).

Description: The Tihange Formation is composed of a lower and upper part. The lower part consists of dark grey, micaceous mudstone with rusty patches (1 mm up to 2 cm in size). In the upper part a coarsening upwards into a coarser part, is followed by a fining upwards until the same grain size as at the base. At the base it consists of light grey, micaceous mudstone (same grain size as the lower part of the Tihange Formation) becoming coarser upwards into coarse to very coarse mudstone with the occurrence of beds up to 5 cm in the coarsest part. Higher up the grain size becomes finer again to mudstone (same grain size as the lower part of the Tihange Formation) with the occurrence of rare beds of coarser mudstone. It becomes darker (but not as dark as the lower part) with the occurrence of rusty patches (the same as for the lower part) in certain layers. A lamination appears when the lithology becomes coarser and disappears when the lithology becomes finer. We prefer to raise this unit to the rank of formation due to its lack of macrofossils and absence of calcareous admixture, which are typical characteristics for the Fosses Formation.

Thickness: Due to the presence of many small faults in the sections where they occur an accurate thickness is difficult to obtain. For the lower part of the Tihange Formation we estimate for the thickness: in the section rue Bonne Espérance 8.7 m; in the section rue Rouge Lion 2.2 m; in the Ruisseau de l'Homme Sauvage it occurs twice with in the northern part approximately 13.8 m and in the southern part approximately 4.4 m. For the upper part of the Tihange Formation we estimate for the thickness: in the section rue Bonne Espérance 9.4 m; in the section rue Rouge Lion 19.3 m; in the Ruisseau de l'Homme Sauvage > 2.8 m.

Fossils, bio- and chronostratigraphy: Brachiopods and trilobites occur in the upper part of the Tihange Formation. The brachiopods belong to the *Hirnantia* fauna (dominated by *Eostropheodonta* cf. *hirnantensis* with a few shells of *Plectothyrella*) indicating a Hirnantian age. The trilobites, not studied in detail, belong to the Family *Dalmanitidae* (Van Roy, pers. comm., 2012).

Bonne Espérance Formation

Name and stratotype: The Bonne Espérance Formation was first defined by Vanmeirhaeghe (2006b) as the Bonne-Espérance Formation. He defined the type locality in the rue Bonne Espérance in the interval between 70 m and approximately 30 m northwest of the southern intersection of the rue Bonne Espérance and the rue Rouge Lion. We define the type locality in the rue Bonne Espérance more exactly from 70 m to 55 m north of the southern intersection of the rue Bonne Espérance and the rue Rouge Lion.

Area and previous records: The Bonne Espérance Formation is, until now, only known from sections from Tihange, eastern part central Condroz Inlier. It has been studied by Malaise (1907), Michot (1932a, 1934, 1954), Martin (1969a) and Vanmeirhaeghe (2006b).

Description: The Bonne Espérance Formation consists of laminated, dark green to dark grey mudstone. It contains eight, centimetric, white, clay levels parallel with the bedding of the surrounding rock with a possible volcaniclastic origin. We accept the definition of Vanmeirhaeghe (2006b) to make a new lithostratigraphical unit that was formerly incorporated in the lower part of the Dave Formation (Michot, 1954).

Thickness: At least 14.3 meter was measured in the section rue Bonne Espérance.

Fossils, bio- and chronostratigraphy: According to Michot (1932a, 1934, 1954) graptolites of the *acuminatus* Biozone and the *modestus* Biozone occur. This has been confirmed by our new collection of fossils and identification by Prof. Dr. J. Zalasiewicz. The graptolites can be located in the upper part (?) of the *acuminatus* Biozone and the covering *atavus* Biozone. Chitinozoans from the *Belonechitina postrobusta* Biozone do occur. Both indicate an age of early to middle Rhuddanian.

Neuville-sous-Huy Formation

Name and stratotype: The Neuville-sous-Huy Formation lend its name to the outcrops located in Neuville-sous-Huy and the neighborhood of this village. A combined-stratotype is selected for the outcrops at Neuville-sous-Huy of the section Parc de la Neuville, section ravine 700 m east of Parc de la Neuville and the section ravine 1200 m east of Parc de la Neuville. The outcrops of the Parc de la Neuville are located along the mamelon 105 and the outcrops along the pathway north, in and just south of the abandoned quarry. In the section of the ravine 700 m east of Parc de la Neuville the outcrops are located approximately in the prolongation of the stone wall before entering the ravine until approximately 156 meters south of this stone wall. In the section of the ravine 1200 m east of Parc de la Neuville the outcrops are located starting approximately 59 meters southwards of the Grand Route until approximately 113 meters southwards of the Grand Route following the pathway.

Area and previous records: The Neuville-sous-Huy Formation is, until now, only known from sections from Neuville-sous-Huy, eastern part central Condroz Inlier. Rocks of this unit were studied by Malaise & Lespineux (1904), Michot (1932a, 1934, 1938, 1954), Martin (1966, 1969a), Van Doorne (1975), Vandevelde (1976), Maes (1976), Maes *et al.* (1978).

Description: The lower part contains grey, green-grey to green compact mudstone alternating with dark grey and green-grey, laminated mudstone. Higher up red mudstone appear. The lower part can be correlated with unit 1 of the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville and units 3 and 4 of the section Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville. The upper part consists of green, green-grey to grey and dark grey mudstone with intercalations of grey coarser mudstone up to coarse mudstone and very fine sandstone. Red mudstone is only present in the finer parts. The green colour is only present in the finer parts of the mudstone. The upper part can be correlated with unit 2 and possibly unit 4 of the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville and units 5, 6, 7 and 8 of the section Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville. Volcaniclastic layers are present in the sections of Neuville-sous-Huy.

Thickness: The thickness is difficult to determine due to the presence of faults and the exact location of the units against each other in the sections of Neuville-sous-Huy is not exactly known. The lower and upper boundary was not observed. In the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville the thickness of unit 1 and unit 2 together is approximately 119.6 meters. In the section Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville the thickness of unit 4, 5, 6, 7 and 8 together is approximately 34.7 meters.

Fossils, bio- and chronostratigraphy: Chitinozoans of the *dolioliformis* and the *longicollis* Biozones have been found indicating the lower and middle Telychian. Graptolites occur from the *turriculatus-crispus* and *griestoniensis-crenulata* Biozones in the lower and upper part of the formation.

Naninne Formation

Name and stratotype: The "Assise de Naninne" was created by Malaise (1900). The type locality is defined in the village of Naninne, 27 m to the north of the crossroad of the rue des Flawnées and the rue de la Sapinière (Michot, 1934 and own observations). We prefer not to assign a certain stratotype as no complete succession is known that displays the entire formation.

Area and previous records: The Naninne Formation occurs in the central part of the Condroz Inlier. Outcrops are described by Malaise (1900, 1910), Lassine (1913a, b), Michot (1928, 1932a, b, 1934, 1944, 1954), Manil & Ubaghs (1940), Ubaghs (1940), Martin (1966, 1969a), Van Doorne (1975), Rombouts (1976), Vandevelde (1976), Maes (1976), Maes *et al.* (1978).

Description: Dark grey, finely laminated mudstone, known as laminated hemipelagites. These are sometimes interbedded with centimetric, grey to dark grey, compact mudstone and sometimes coarser mudstone is present. A level of limestone nodules occurs. Beds of green, grey-green, green-grey to grey mudstone of multiple meters together with red mudstone intervene with the dark grey, finely laminated mudstone. In the lowermost part of the formation at the section of Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville a volcaniclastic layer occurs. Five pale clayey levels are observed of volcaniclastic origin in the section of Neuville-sous-Huy, new road 300 m west of Parc de la Neuville.

Thickness: No thickness estimate is possible because of observational hiatuses. Michot (1954, 1957) deduced a total thickness of the Wenlock part (*murchisoni* to *ludensis* Biozone) of 350 meters.

Fossils, bio- and chronostratigraphy: At Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville *Conochitina acuminata* occurs starting in the *lapworthi* graptolite Biozone (upper Telychian; Verniers *et al.*, 1995; Nestor, 2012). Graptolites of the *insectus-centrifugus* Biozones occur in the sections of Neuville-sous-Huy, ravine 700 m and 1200 m east of Parc de la Neuville. In the Parc de la Neuville *Margachitina margaritana* is found. Graptolites of the *murchisoni* Biozone are found at Le Roux, Fosses-la-Ville, Naninne and Tihange (Lassine, 1913a, b; Michot, 1928, 1932a, 1932b, 1934); graptolites of the *riccartonensis* Biozone at Le Roux and Naninne (Michot, 1932b, 1934). Manil & Ubaghs (1940) describes the *rigidus* Biozone at Hautes Calenges and the same biozone is encountered in the Parc de la Neuville along the southern pond by Rombouts (1976), Maes *et al.* (1978) and confirmed by our study. Graptolites of the *rigidus-lundgreni* and *lundgreni* Biozones are found at the section Neuville-sous-Huy, new road 300 m west of Parc de la Neuville. In the same section *Sphaerochitina lycoperdoides* is found indicating the upper Homerian. All these data indicate an age of late Telychian to latest Homerian.

Thimensart Formation

Name and stratotype: The "Assise de Thimensart" was created by Malaise (1900) and emended by Michot (1954). It lends its name from the old farm of Thimensart in Fosses-la-Ville. The stratotype is defined on the right bank of the Ruisseau de la Fuette just south of the place called "Le Cheslon" (Martin, 1969a). The outcrops are small and discontinuous along the brooklet and we prefer to extend the stratotype to the outcrops present in Neuville-sous-Huy along the eastern path of the southern pond of Parc de la Neuville between approximately 22.8 and 63.7 meters south of the dam between the middle and the southern pond.

Area and previous records: The Thimensart Formation occurs in the central Condroz Inlier. Outcrops are described by Malaise (1887, 1890, 1900), Lassine (1913a, b), Michot (1928, 1932b, 1934), Ubaghs (1940), Martin (1969a), Van Doorne (1975), Rombouts (1976), Maes *et al.* (1978).

Description: The Thimensart Formation consists of grey, olive green, green-grey to grey-green mudstone sometimes slightly coarser but still mudstone. Both compact and laminated mudstone occurs. One red mudstone bed of 4 mm thick is observed in the section of Neuville-sous-Huy, Parc de la Neuville along the southern pond.

Thickness: It is difficult to determine a thickness as no complete section covering the whole formation have been observed. The sediments along the southern pond of Parc de la Neuville and belonging to this formation have a thickness of approximately 28.6 meters and belong only to the middle and lower part of the upper Gorstian, hence not covering the whole formation. Moreover faults are present limiting an exact thickness measurement. Michot (1954, 1957) estimates the thickness in the order of 100 meters.

Fossils, bio- and chronostratigraphy: Besides graptolites also brachiopods, trilobites, crinoids, orthocone nautiloids, conularia and ostracods are found (Lassine, 1913b; Rombouts, 1976, Maes *et al.*, 1978, own observations). Graptolites of the *nilssoni* (Naninne, Fosses-la-Ville, Tihange; Malaise, 1887, 1890, 1900; Lassine, 1913a; Michot, 1932b, 1934; Ubaghs, 1940), *scanicus* (Naninne, Fosses-le-Ville, Neuville-sous-Huy; Michot, 1932b, 1934; own results) and *tumescens* (Vitrival, Tihange; Michot, 1928, 1934; Ubaghs, 1940) Biozones have been reported indicating the Gorstian. The chitinozoans along the southern pond of Parc de la Neuville indicate a range of the Baltoscandian *Ancyrochitina desmea* Biozone to the lower part of the Baltoscandian *Angochitina elongata* Biozone corresponding to the middle Gorstian to lower part of the upper Gorstian.

Criptia Group

Name and stratotype: Michot (1928) was the first who mentions rocks from the "Plateau de Criptia" as "schistes de Criptia". The unit was defined by Delcambre & Pingot in Verniers *et al.* (2001), after mapping for the new geological map of these authors published in 2004. Vanmeirhaeghe (2006b) defines the stratotype in Sart-Eustache, in the Parc de Sart-Eustache section in the eastern limb of the valley of the Ruisseau de l'Étang du Diable, between the boundary with the Génicot Formation (approximately 155 m north of the southern stone entrance of the Parc) and the church of Sart-Eustache.

Area and previous records: The Criptia Group occurs in the Puagne Inlier. Outcrops have been studied by Michot (1928), Billiaert (2000), Herbosch *et al.* (2002); Delcambre & Pingot, 2004, Boucquet (2006), Vanmeirhaeghe (2006b).

Description: The rocks of this unit at Sart-Eustache, Parc de Sart-Eustache consists of (dark) green-grey to grey mudstone. Delcambre & Pingot (2004) define the unit as consisting of shale to silty shale. A unit of green to grey-green shale can be distinguished and a more darker coloured, silty unit occurs higher up according to these authors.

Thickness: The thickness is tentatively estimated at several hundred meters.

Fossils, bio- and chronostratigraphy: *Belonechitina postrobusta*, *Conochitina electa* and *Conochitina iklaensis* are found by Billiaert (2000) in the lower part of the Criptia Group indicating the upper Rhuddanian to Aeronian according to him. According to Vanmeirhaeghe (2006b) *Belonechitina postrobusta* was too prematurely identified and *Conochitina electa* was misidentified in the study of Billiaert (2000). Vanmeirhaeghe (2006b) finds *Belonechitina* cf. *postrobusta*, *Ancyrochitina ancyrea*, *Spinachitina* sp. A, *Spinachitina* spp. and *Cyathochitina* spp. According to us the identifications of Billiaert (2000) are correct looking at the plates and *Belonechitina* cf. *postrobusta* of Vanmeirhaeghe (2006b) are specimens of *Belonechitina postrobusta* also by looking at the plates. Moreover we find specimens of *Belonechitina postrobusta*, *Cyathochitina kuckersiana* and *Cyathochitina* spp. According to Vanmeirhaeghe (2006b) the Criptia Group is younger than the underlying Génicot Formation. The age of the Criptia Group is still under question but a late Llandovery to tentatively Pridoli age is proposed. We do not follow Vanmeirhaeghe (2006b) to correlate (at least a part of) the Criptia Group with the newly defined Neuville-sous-Huy Formation.

2. Depositional environment of the lithostratigraphical units of the Condroz Inlier

The depositional environment of the Condroz Inlier is regarded as a shelf environment (Verniers *et al.*, 2002a). Vanmeirhaeghe (2001a) has proven the existence of turbidites in the Ombret Formation belonging to the Ombret Inlier. The Ombret Inlier is interpreted as belonging to a part of the Brabant Basin but is now part of the Condroz Inlier (Vanmeirhaeghe, 2001a, b; Vanmeirhaeghe & Verniers, 2002; Valcke & Debacker, 2002). Vanmeirhaeghe (2006b) interpreted all the other lithostratigraphical units of the Ordovician and some of the Silurian to be shelf deposits.

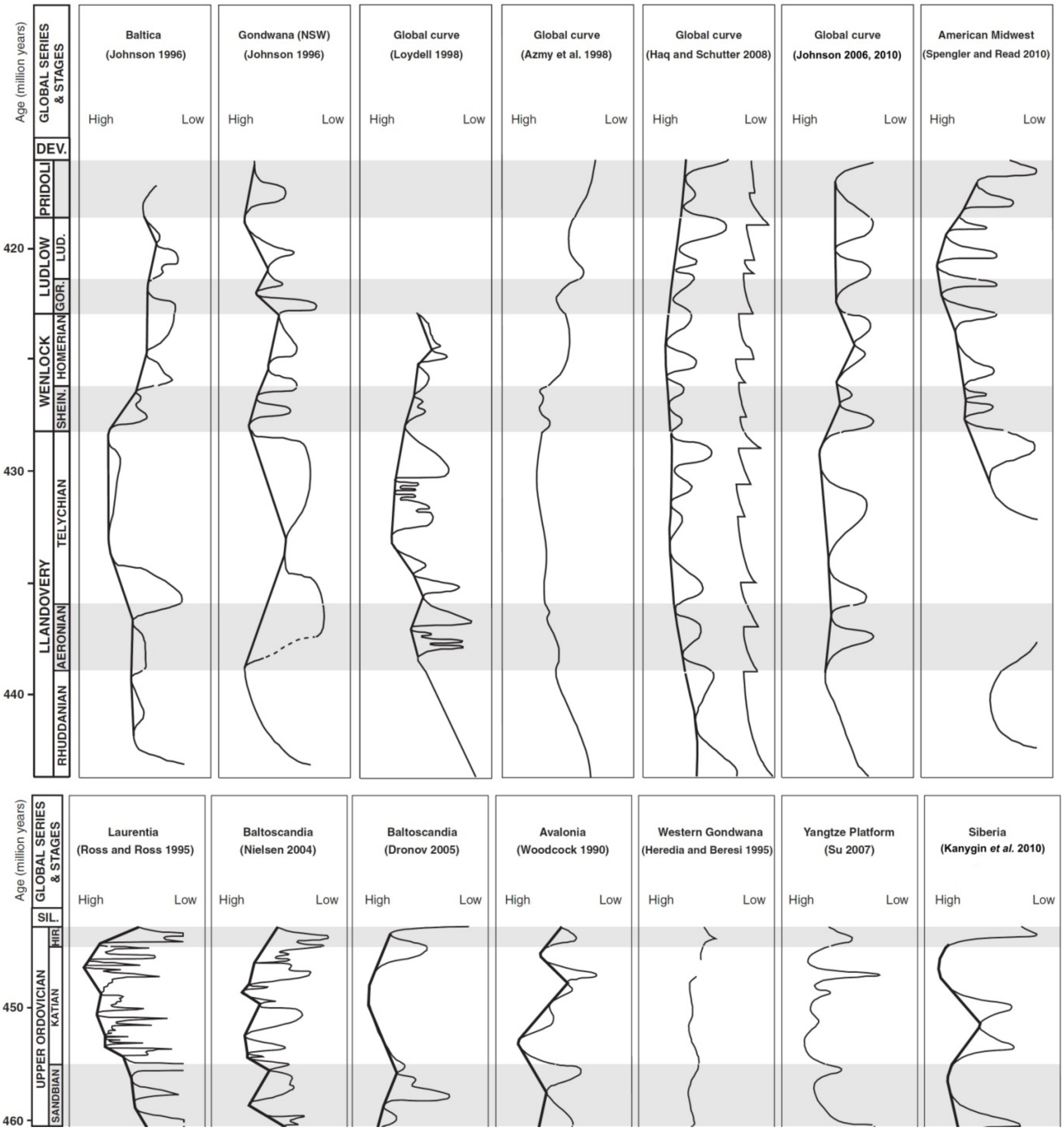


Fig. III.2.1. Sea level curves of the Upper Ordovician (at the base) and Silurian (at the top). Adapted from Munnecke *et al.* (2010). Note that sea-level curves have to be critically interpreted.

The lithostratigraphical units of the Tihange section (chapter II.1) and the lithostratigraphical units of the Silurian of the Condroz Inlier display a shelf environment although the position on the shelf changes through time. Most of the time a deep shelf environment exists. The shelf environment is supported by the lack of turbidites and the diversified presence of graptolites in many layers.

A deepening trend is observed in the Fosses Formation from the Bois de Presles Member to the Faulx-les-Tombes Member (Vanmeirhaeghe, 2006b). We observed also tempestites in the Tihange section belonging to the Bois de Presles Member followed upwards by green-grey, bioturbated mudstone lacking the tempestites and the presence of graptolites indicating a deeper environment. The brachiopods of the upper part of the Tihange Formation indicate a Benthic Assemblage 3 indicating a shallower environment. An eustatic sea-level drop is known at that time (see fig. III.2.1) corresponding to the shallower deposition in Tihange. The Bonne Espérance Formation is deposited in a deeper environment lacking bioturbation. Hence the lamination is preserved.

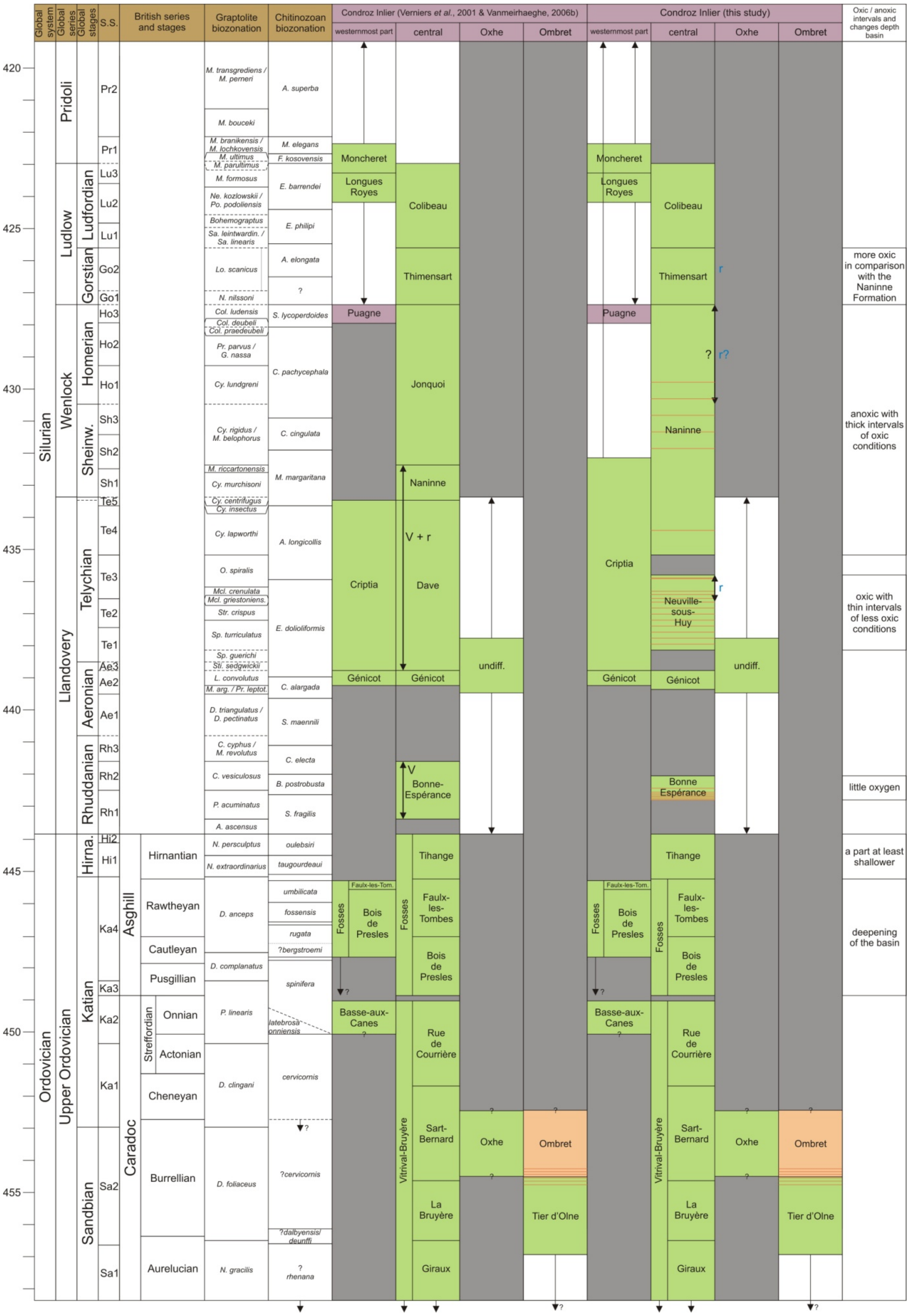
Starting from the Neuville-sous-Formation in the lower Telychian shifts are observed of the colour green to dark grey and compact and laminated mudstone. This indicates changes in the position of the oxic-anoxic front through time in the water column. Deposition took place on the outer shelf but shifts of this position are present.

In the Neuville-sous-Huy Formation the deposition took generally place in the oxic water column. The laminated parts with dark grey mudstone, alternated with green-grey mudstone, are deposited in less oxic conditions.

An important lihological change takes place between the Neuville-sous-Formation and the Naninne Formation. The Neuville-sous-Huy Formation contains compact mudstone with some laminated levels where graptolites are present in these levels. The Naninne Formation is composed of mainly dark grey, finely laminated mudstone interpreted as laminated hemipelagites. We assign this change to a change in the position of the oxic-anoxic front. The laminated hemipelagites indicate an anoxic environment. The transition takes place in the upper part of the *spiralis* Biozone. It is for the first time that the facies of laminated hemipelagites is described from the Condroz Inlier.

In the Naninne Formation, besides the laminated hemipelagites, compact levels of green, grey-green, green-grey and grey mudstone also occur of several meters thick. It indicates that these beds are deposited in more oxic conditions.

The laminated hemipelagites of the Naninne Formation are replaced in the Gorstian by greyish to greenish, sometimes laminated mudstone where a benthic fauna is sometimes present. This lithology indicates that the water column becomes more oxic.



S.S.
British series and stages
Graptolite biozonation
Chitinozoan biozonation
Condroz Inlier (Verniers et al., 2001 & Vanmeirhaeghe, 2006b)
Condroz Inlier (this study)
westernmost part
central
Oxhe
Ombret
Oxic / anoxic intervals and changes depth basin
Silurian
Ordovician
Pridoli
Ludlow
Wenlock
Llandovery
Upper Ordovician
Ludfordian
Gorstian
Homerian
Sheinw.
Telychian
Aeronian
Rhuddanian
Hirna.
Katian
Sandbian
Moncheret
Longues Royes
Colibeau
Thimensart
Puagne
Jonquoi
Naninne
Criptia
Dave
Génicot
undiff.
Bonne-Espérance
Neuville-sous-Huy
Tihange
Faulx-les-Tombes
Bois de Presles
Fosses
Basse-aux-Canes
Rue de Courrière
Sart-Bernard
La Bruyère
Giraux
Vitrival-Bruyère
Tier d'Olne
more oxic in comparison with the Naninne Formation
anoxic with thick intervals of oxic conditions
oxic with thin intervals of less oxic conditions
little oxygen
a part at least shallower
deepening of the basin

Fig. III.2.2. Previous page. Litho-, bio- and chronostratigraphy of the Condroz Inlier with an overview of the changes of the depth of the basin; for younger sediments changes in the amount of oxygen in the water column at the place of deposition are given. The same legend has been used as in figure III.1.1. Volcaniclastic layers are indicated with an orange line (or abbreviated with the letter "V"); the location of red mudstone in the stratigraphy is given (abbreviated with the letter "r"). Note that before our study the location of many volcaniclastic layers and the red mudstone in the chronostratigraphy was not exactly known The chronostratigraphy, numerical ages and graptolite biozonation are from Gradstein *et al.* (2012). The stage slices for the Upper Ordovician are from Bergström *et al.* (2009), these for the Silurian are from Cramer *et al.* (2011a), the chitinozoan biozonation of Avalonia for the Upper Ordovician is from Vandenbroucke (2008b), the Silurian global chitinozoan biozonation is from Verniers *et al.* (1995).

3. An evolutionary model for the middle Katian to Silurian of the Condroz-Brabant basin

see fig. III.3.1

We will discuss below the evolution of the basin where the sediments of the Condroz Inlier and the Brabant Massif are deposited for the middle Katian to Silurian. The lower boundary corresponds to the start of megasequence 3 of Verniers *et al.* (2002a). A correlation of the present lithostratigraphical units will also be discussed and the depositional setting.

An important feature that we notice is that the sediments of the Brabant Massif during megasequence 3 are always deposited in deeper circumstances in comparison with the sediments of the Condroz Inlier.

Megasequence 3 starts in the Brabant Massif with the deposition of the Madot Formation. This formation has a calcareous admixture and an equivalent is found in the Condroz Inlier in the Bois de Presles Member of the lower part of the Fosses Formation. They contain both a macrofauna of brachiopods, trilobites, bryozoans, echinoderms (a.o. cystoids and crinoids), corals and the Bois de Presles Member also ostracods, sponges, molluscs and algae (Tourneur *et al.*, 1993; Vanmeirhaeghe, 2006b; Herbosch & Verniers, 2014). The Madot Formation is however deposited in a deeper environment in comparison with the Bois de Presles Member but still situated on the shelf. No tempestites are found in the Madot Formation. The Bois de Presles Member and the covering Faulx-les-Tombes Member are diachronous through the Condroz Inlier (Vanmeirhaeghe, 2006a, b). These two members, belonging to the Fosses Formation ranges from the Pusgillian to the Rawtheyan (middle to upper Katian) containing the chitinozoan biozones of the *Fungochitina spinifera*, *Tanuchitina bergstroemi*, *Conochitina rugata* and *Bursachitina umbilicata* Biozones (Vanmeirhaeghe, 2006b). The Madot Formation of the Brabant Massif ranges from the lower Pusgillian to lower Rawtheyan (middle to upper Katian) and contains the chitinozoan biozones of the *Fungochitina spinifera*, possibly the *Tanuchitina bergstroemi* (Vanmeirhaeghe *et al.*, 2005) and the *Conochitina rugata* Biozone. The calcareous admixture in the Madot Formation and the Bois de Presles Member with the presence of a rich macrofauna can be correlated to the Boda event (Fortey & Cocks, 2005) corresponding to a global warming episode. In the Condroz Inlier there is a deepening of the basin from the Bois de Presles Member, brachiopods indicate a Benthic Assemblage 4-5 and microfacies analyses suggest a level close to the storm wave base (Préat in Vanmeirhaeghe *et al.*, 2005), towards the Faulx-les-Tombes Member deposited in a zone of Benthic Assemblage 5-6 (Sheehan, 1987; Vanmeirhaeghe, 2006b).
The Madot Formation contains multiple volcaniclastic rocks while in the Fosses Formation in the Condroz Inlier no volcaniclastic rocks are observed.

No hiatuses are expected in the transition from the Madot Formation to the Brûtia Formation in the Brabant Massif although the contact between these formations is nowhere observed. An interesting correlation can be made from the Condroz Inlier to the Brabant Massif in the interval of the Rawtheyan (late Katian) to Hirnantian. The facies of the Goutteux Member (lower part of the Brûtia Formation), present as green-grey mudstone with dark grey, ellipsoidal bioturbations) is comparable with the facies of the Faulx-les-Tombes Member, upper part of the Fosses Formation (known as "schistes mouchetés") in the Condroz Inlier (described in Vanmeirhaeghe & Verniers, 2004 for the Puagne Inlier; Vanmeirhaeghe, 2006a in Faulx-les-Tombes for the central Condroz Inlier; section of Tihange, chapter II.1). Although no dark grey zones are present in the Faulx-les-Tombes Member. It has been deposited in the Puagne Inlier during the upper Rawtheyan (uppermost Katian) and in Faulx-les-Tombes during the lower to upper Rawtheyan (upper Katian). Hence it implies that it has been deposited just before the Hirnantian glaciation and sea-level drop. The general idea is that during the latest Ordovician the sediments of the Brabant Massif were deposited in a deeper environment in comparison with the Condroz Inlier but all in the same basin (Verniers *et al.*, 2002a). Hence a possible shift can be expected from the Condroz Inlier to the Brabant Massif during the glaciations and consequently sea level fall during the lower Hirnantian. The sediments of the Brûtia Formation in Hennuyères were deposited during the upper Hirnantian when the sea level was again rising (Brenchley, 2004) at that time. In most sea level reconstructions (for an overview of different sea-level curves in the Upper Ordovician we refer to fig. III.2.1) the sea level was still not so high in the upper Hirnantian as in Rawtheyan (late Katian) times but it was rising. So a possible facies shift of the Condroz Inlier to the Brabant Massif during the upper Hirnantian is feasible within this hypothesis.

During the Hirnantian the Goutteux Member of the Brûtia Formation of the Brabant Massif was deposited on the deep shelf. In the Condroz Inlier at the same time the Tihange Formation is deposited in shallower conditions belonging to Benthic Assemblage 3 corresponding to a position on the shelf below mean fair weather base but above storm wave base.

The upper part of the Brûtia Formation (Nivelles Member) is characterized by a thick fine-grained tuff that is present between Nivelles and Gembloux, the "eurite of Grand-Manil" (*in litteris*) in the Orneau valley (40 m thick; Delcambre & Pingot, 2002) or the "eurite of Nivelles" (in litteris) in the Thisnes valley (50 m thick; Mourlon, 1900). Graptolites found in slates just below the "eurite of Grand-Manil" belong to the *cyphus* Biozone (Elles in Maillieux, 1930). Graptolites in the same levels mentioned in Gerlache (1956) and determined by Bulman (1950) as *Climacograptus scalaris* indicate the *acuminatus* Biozone or slightly above or below. Graptolites described from the eurite of Nivelles belong clearly to the *vesiculosus* Biozone (Rickards in Verniers & Van Grootel, 1991). This means that in both valleys the Nivelles Member has a Rhuddanian age. The Bonne Espérance Formation in the Condroz Inlier contains graptolites indicative for the upper part (?) of the *acuminatus* Biozone and the covering *atavus* Biozone. Chitinozoans indicate the *Belonechitina postrobusta* Biozone. Hence the Bonne Espérance Formation indicates an age of lower to middle Rhuddanian. The Bonne Espérance Formation contains possibly volcaniclastic layers (eight centimetric beds in total). Hence we correlate the Bonne Espérance Formation with the Nivelles Member of the Brûtia Formation. The lamination, present in the Bonne Espérance

Formation, indicates that no bioturbation took place disturbing the lamination. A deposition on the outer shelf is expected for this formation.

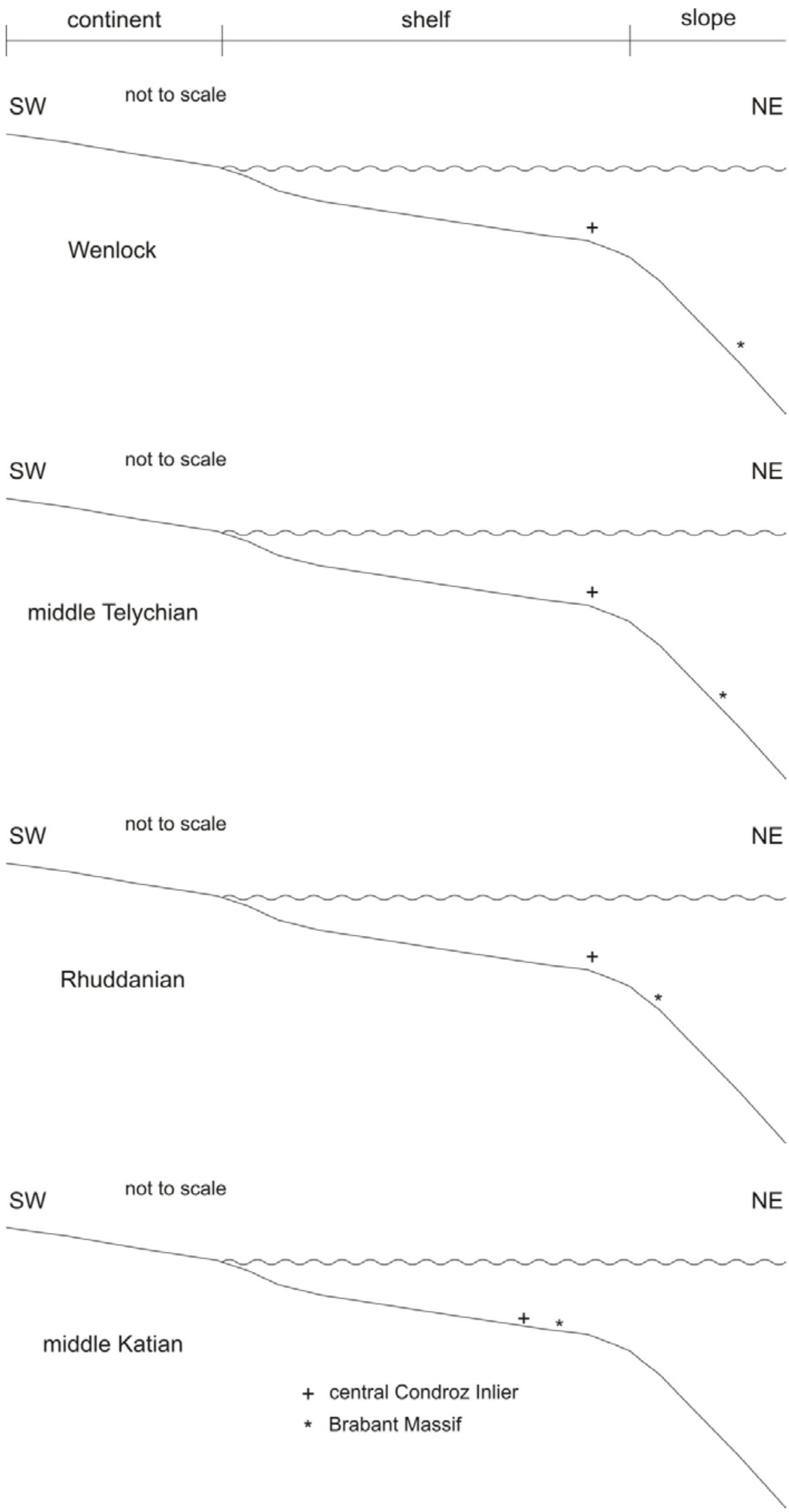


Fig. III.3.1. Overview of the place of deposition of the sediments of the central Condroz Inlier (indicated with a “+”) and the Brabant Massif (indicated with a “*”) on the shelf-slope. Starting from the Telychian oxic-anoxic changes are present in the central Condroz Inlier. Note that these figures are not to scale and sea-level changes are not drawn.

The volcaniclastic layer at the top of the Brûtia Formation is not encountered in the Deerlijk Formation. Only a siliceous lutite, 1.4 m thick, of possible volcaniclastic origin is described by Legrand (1966) in the *acuminatus* Biozone of the Deerlijk 404 borehole. It indicates, with or without prove of volcaniclastic origin of the siliceous lutite, that the volcanic activity causing the deposition of the volcaniclastic layer decreases in the direction from the region Nivelles - Grand-Manil towards West Flandres.

The Madot Formation has been deposited during the lower Pusgillian to lower Rawtheyan (middle to upper Katian). When we look at the sediments of the Brûtia Formation (the Goutteux Member) we do not see a shallower facies. Furthermore the facies of the Goutteux Member is comparable with the facies of the Faulx-les-Tombes Member in the Condroz Inlier. It has been proven that this facies is deposited in a deeper environment in comparison with the underlying Bois de Presles Member that can be correlated with the Madot Formation but deposited in shallower conditions. Hence we assume a deepening trend from the Madot Formation to the Brûtia Formation. This is remarkable as the Hirnantian is known for an eustatic sea-level fall (see fig. III.2.1.). Hence the basin of the Brabant Massif is shifting to a deeper environment already in the upper Katian.

In the outcrop area of the Brabant Massif the Bois Grand-Père Formation covers the Brûtia Formation. The Bois Grand-Père Formation consists of dark greenish grey shale or slate at the base and medium to dark grey shale or slate, interbedded with many medium grey laminated siltstone beds and fine-grained, laminated (sometimes oblique) sandstone. The Bois Grand-Père Formation is partly deposited as turbidites (Verniers *et al.*, 2001; Delcambre & Pingot, 2002), but it is poorly known due to its poor degree of exposure. Graptolites are described belonging to the *cyphus*, *convolutus* and *crispus* Biozones (Maillieux, 1930, 1933; Michot, 1930) indicating the upper Rhuddanian to the lower-middle Telychian.

In boreholes in West Flandres the Deerlijk Formation is described. It contains centimetric to decimetric fining upwards cycles from light grey sandstone to medium grey shale. Black graptolitic shale occur in between. The deposits of the Deerlijk Formation are interpreted as turbidites and laminated hemipelagites by Verniers & Van Grootel (1991). Graptolites of the *acuminatus*, *vesiculosus*, *cyphus*, *gregarius*, *convolutus* and *sedgwickii* Biozones are described by Legrand (1966, 1968) indicating the Rhuddanian and the Aeronian. Maletz (1999) restudied the graptolites of the Deerlijk 404 borehole and confirmed the presence of the *acuminatus* and the *vesiculosus* Biozones. Van Grootel *et al.* (1998) restudied the graptolites in boreholes reaching Aeronian sediments and found graptolites indicating the *triangulatus*, *magnus*, *leptotheca*?, *convolutus* and *sedgwickii* Biozones. The chitinozoans indicate the *maennili* and *alargada* global Biozones for these sediments (Van Grootel, 1990; Van Grootel *et al.*, 1998). Hence a Rhuddanian and Aeronian age is assigned. The covering Lust Formation is comparable with the Deerlijk Formation but it contains more sandstone beds (Legrand, 1961; Martin, 1969a; Verniers *et al.*, 2001). Graptolites belong to the *turriculatus* and *crispus* Biozones according to Legrand (1961). Van Grootel *et al.* (1998) describe in boreholes the *guerichi* Biozone (with the *gemmatus*, *renaudi*? and *utilis*? Subzone) and the *crispus* Biozone. Chitinozoans indicate the *dolioliformis* global Biozone (Van Grootel *et al.*, 1998). Hence the Lust Formation can be placed in the lower Telychian (Van Grootel, 1990; Van Grootel *et al.*, 1998).

Similarities are noted between the Bois Grand-Père Formation and the Deerlijk, Lust Formations defined in boreholes in West Flandres: e.g. the dominantly grey colour, the thin bedded sometimes obliquely laminated fine sandstone. But the Bois Grand-Père Formation differs in lacking the high proportion of dark graptolitic shale (Verniers *et al.*, 2001).

Verniers *et al.* (2002a) considered a division of two areas where sediments are deposited in the Brabant Massif starting from the middle Llandovery: a deep shelf environment in the southwestern Brabant Massif (south of the Ronse-Veurne line) and a turbiditic environment on the slope for the outcrop area, the central and north of the Brabant Massif. This model needs reconsideration. Legrand (1966) describes in the boreholes of Deerlijk (Deerlijk 18 and 404 boreholes), corresponding to the Deerlijk Formation, a rhythmic pattern in the sedimentation of sandstone going into shale. Martin (1971) describes also this rhythmic pattern in the Deerlijk 404 borehole. Verniers & Van Grootel (1991) interpret the deposits of the Deerlijk Formation as turbidites and laminated hemipelagites. Van Grootel (1990) describes in boreholes of West Flandres belonging to the Deerlijk or Lust Formation turbidite deposits. Moreover in the borehole of Lust (Kortrijk 83W44) where the Lust and Deerlijk Formations are present, the following ichnofossils are found (Legrand, 1961): *Planolites montanus*, *Nereites sedgwikii* and *Dyctiodora liebeana*. They indicate a deep deposition from the continental edge to the abyssal plane (Van Grootel, 1990). Vanmeirhaeghe (2006b) uses a different approach to question a shelf environment for the southwestern part of the Brabant Massif during the Silurian. He identifies in a borehole in Harelbeke, corresponding to the Goutteux Member, sediments that are deposited probably on the outer shelf to upper slope. The *Spinachitina taugourdeaui* Biozone is identified indicating the lower or lower upper Hirnantian. Sea-level was lowered at that time (see fig. III.2.1.) and after that period the sea-level is rising, expecting deeper environments of deposition. He recognized also the presence of turbidites in the Deerlijk Formation.
Turbidites are preferably deposited in slope environments. In the Deerlijk and the Lust Formations in the southwestern part of the Brabant Massif turbidites are present, although thin bedded, indicating the deep environment on the slope. In the outcrop area turbidites are also present in the Bois Grand-Père Formation that is time equivalent. Hence we prefer to abandon the use of two sedimentary areas starting from the middle Llandovery. Sediments are deposited on the slope during the Silurian in the Brabant Massif and no distinction is made between the southwestern part of the Brabant Massif and the other main part of the Brabant Massif. This model agrees also to the observation of turbidites in the Bellegem and the

Rekkem Formations in the upper Silurian to lowermost Lochkovian situated in the southwestern part of the Brabant Massif.

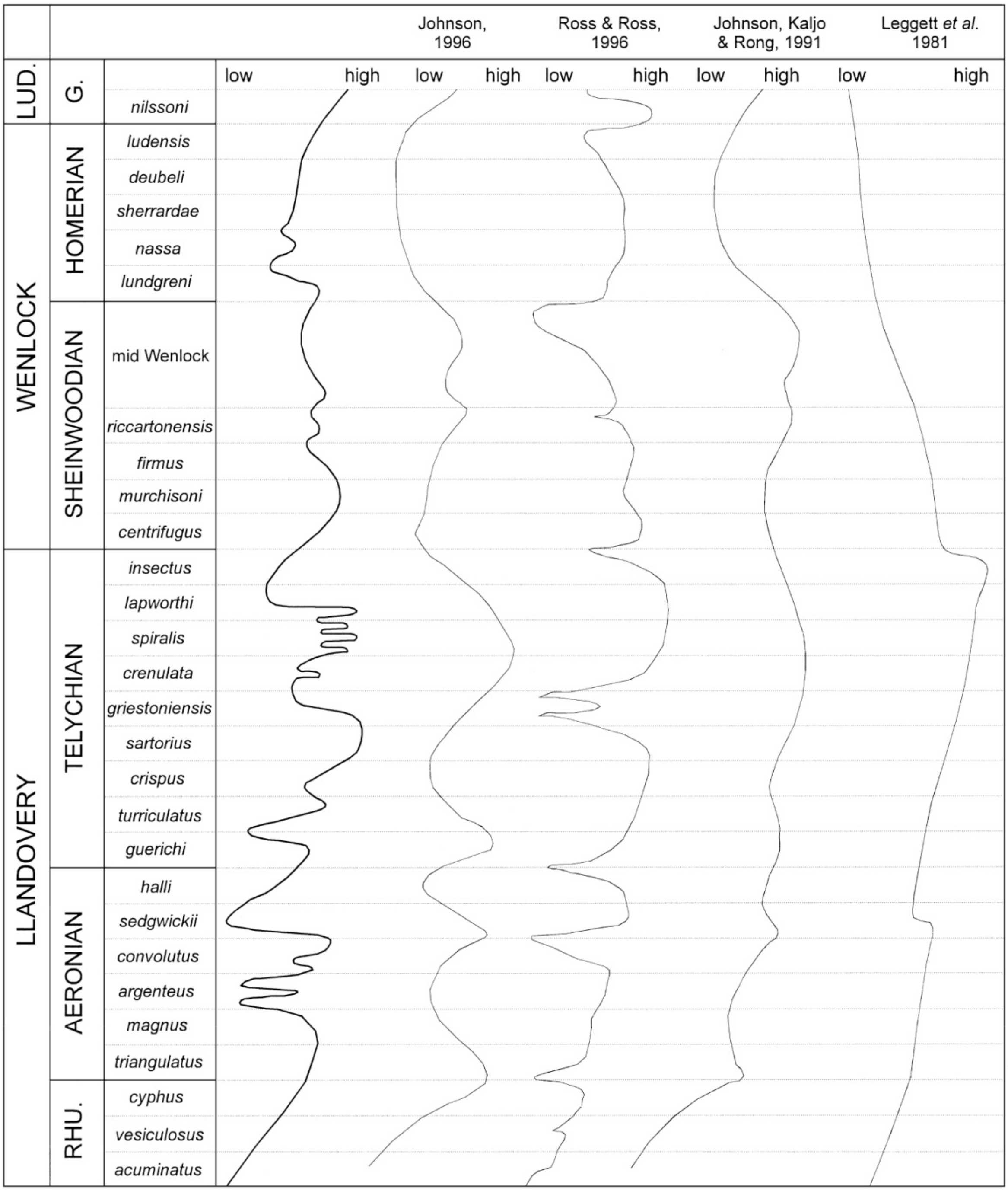


Fig. III.3.2. On the left sea-level curve of Loydell (1998). From Loydell (1998).

Starting from the Llandovery sediments are deposited on the slope in the Brabant Massif as turbidites whilst in the Condroz Inlier sediments are deposited on the shelf. Hence differences in the Condroz-Brabant basin caused by sea-level fluctuations is almost only recognized in the Condroz Inlier. A correlation of the units of the Condroz Inlier with these of the Brabant Massif is mostly meaningless albeit below a correlation has been made.

A shelf environment persisted in the Condroz Inlier during the Silurian. An observational gap exists between the Bonne Espérance Formation and the Génicot Formation but we expect that sedimentation was continuous in the eastern part of the Condroz Inlier. As noted earlier Vanmeirhaeghe (2006b) saw a hiatus spanning from the Hirnantian to early Aeronian in the western Condroz Inlier and assumed that the sedimentation was continuous in the eastern Condroz Inlier. This assumption is proven in our study by the sediments of the Tihange Formation and the Bonne Espérance Formation although observational hiatuses are present in the eastern Condroz Inlier.

For the first time the Génicot Formation has been proven to occur in the eastern Condroz Inlier. These sediments are the first deposits in the western Condroz Inlier, Puagne Inlier after a hiatus spanning the Hirnantian to lower Aeronian. We assume that starting from the deposition of the Génicot Formation and certainly at the end of it the depth of the basin of the western and eastern Condroz Inlier is the same. The Génicot Formation can be correlated with the Brabant Massif with a level corresponding to the upper part of the middle Aeronian to the lower part of the upper Aeronian in the Bois Grand-Père Formation and the Deerlijk Formation.

In the Sint-Antonius borehole (Kortrijk 83W421) a three centimeter thick tuff belonging to the *convolutus* Biozone is described in the Deerlijk Formation. No volcaniclastic layers are found in the Aeronian of the Condroz Inlier.

A deepening trend is observed from the Génicot Formation to the Neuville-sous-Huy Formation in the Condroz Inlier although an observational gap occurs between these two units. The mudstone of the Neuville-sous-Huy Formation together with the occurrence of many graptolite levels point to a deep environment on the shelf, probably outer shelf.

Several coarser and finer levels occur in the upper part of the Neuville-sous-Huy Formation. They do not reflect turbidites as we have not seen a gradual fining into a certain direction as is the case with turbidites. We do not know the depth of deposition of these coarser levels but a shallower environment is expected. Hence in the upper part of the Neuville-sous-Formation changes in the depth of the basin occur related to relative sea-level changes. The base of the upper part of the Neuville-sous-Huy Formation can be correlated with a level in the *crenulata* Biozone. It extends up to the lower part of the *spiralis* Biozone (based on correlation with chitinozoans). The eustatic sea-level curve of Loydell (1998) shows in this interval several eustatic sea-level changes (see fig. III.3.2). They can be possibly correlated to changes in the depth of the basin. But as noted earlier the interpretations of these eustatic sea-level curves should be handled cautious.

A volcanic complex is present in the region of Voroux-Goreux in an eight km long subcrop gallery for water transport. However not so much biostratigraphical information is available about this volcanic complex. Graptolites of the *convolutus* Biozone are found (Michot, 1930). According to Verniers & Van Grootel (1991) a considerable section of Llandovery and Wenlock rocks is present in the subcrop galleries of Voroux-Goreux. Hence this volcanic activity can be correlated with the volcaniclastic layers present in Neuville-sous-Huy but also with the volcaniclastic layer of Pitet in the Mehaigne valley of the Brabant Massif.

The Madot Formation, during the middle to upper Katian, is deposited in a shelf environment. The lower part of the Brûtia Formation, the Goutteux Member, is deposited in deeper circumstances but still on the shelf during the Hirnantian. This is remarkably as a sea-level drop occurs in that time slice although deeper sediments are deposited. Hence a deepening of the basin of the Brabant Massif is started in the upper Katian. At the base of the Silurian a slope setting starts to prevail in the Brabant Massif.

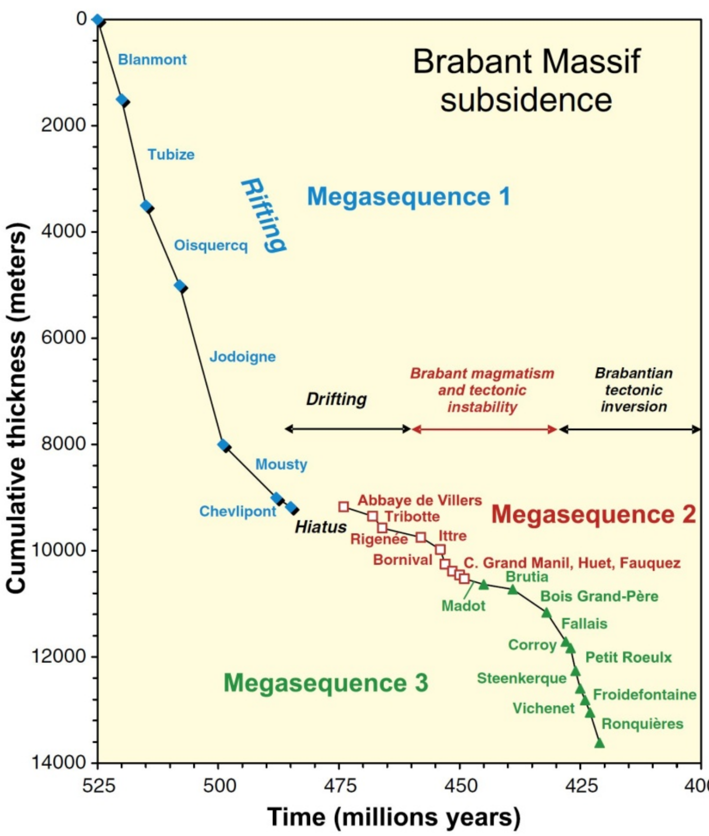


Fig. III.3.3. Cumulative thickness curve of the Lower Palaeozoic sediments of the Brabant Massif. From Linnemann *et al.* (2012).

The deepening of the basin of the Brabant Massif starts in the upper Katian. When considering the thickness curve of the formations in the Brabant Massif (see fig. III.3.3) we see that thick sediment beds start to deposit in the Fallais Formation (upper Telychian).

Although the thickness of the deposits gently increase starting in the Llandovery with the Bois Grand-Père Formation. Hence a diachronism is present between the deepening of the basin, starting in the upper Katian, and thick sediment deposits in the Brabant Massif, starting in the upper Telychian. In the Llandovery we see a gentle increase of the presence of turbidites with the Latinne Formation in the upper Telychian as containing only turbiditic sediments. It can be questioned to place exactly the start of the foreland basin. It can be placed on the start of the turbidites (Van Grootel *et al.*, 1997; Debacker, 2001; Verniers *et al.*, 2002a) or it can be placed on the start of the deepening of the basin. The turbidites are thinly bedded in the Llandovery of the Brabant Massif and become gradually thicker towards the upper Telychian where mainly a turbiditic sedimentation takes place. The deepening of the basin starts however in the upper Katian and this can be placed more exactly than the dominance of the turbidite deposits. Hence we prefer to place the start of the foreland basin in the upper Katian between the top of the Madot Formation and the Brûtia Formation.

The Naninne Formation, with the deposition of laminated hemipelagites, means an introduction to an anoxic environment. We have not seen the presence of any turbidites in the Naninne Formation, hence a position on the outer shelf to upper slope is expected. The laminated hemipelagites are introduced gradually with at the base still the presence of compact mudstone correlated with the *lapworthi* Biozone. Higher up the laminations become more prominent until only a dark grey, finely laminated mudstone occurs observed in the *insectus-centrifugus* Biozone. Hence a transition to an anoxic environment takes place between the *lapworthi* and the *insectus-centrifugus* Biozones.
When we compare the Condroz Inlier with the Brabant Massif the sediments of the Fallais Formation correspond to the lower part of the Naninne Formation.

A volcaniclastic layer occurs in the Fallais Formation, known as the volcaniclastic layer of Pitet in the Mehaigne valley. This volcaniclastic layer shares the same petrographical characteristics as the “arkose” present in Neuville-sous-Huy that we consider as three (maybe four) different levels. It is interbedded between sedimentary deposits that are turbidites. Verniers (1983) recognizes the characteristics of a turbidite in the volcaniclastic layer of Pitet and proposes that an igniturbidite has deposited the volcaniclastic layer. The estimated thickness of the volcaniclastic layer of Pitet is 31 m. The volcaniclastic layer of Pitet can be correlated to the upper Telychian due to the presence of *Conochitina acuminata* below and above the layer. Hence only one volcaniclastic layer present in Neuville-sous-Huy can be possibly correlated with the volcaniclastic layer of Pitet: volcaniclastic layer Vγ of the section of Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville.
A remarkably thickness variation exists between the volcaniclastic layer of Pitet and Vγ: the thickness of the volcaniclastic layer of Pitet is estimated at 31 m; the thickness of Vγ is 3.08 m + ±0.5 m(?). However we assume that these volcaniclastic layers can change considerably in thickness from one place to another. A correlation of the volcaniclastic layers can only been done using biostratigraphy of the sediments where these volcaniclastic layers are deposited.

Interesting is the thickness variation of the volcaniclastic layer of Pitet occurring in the Fallais Formation and the position of this layer. In the Mehaigne valley the thickness is 31 meters and the top occurs approximately 135 meters below the top of the Fallais Formation (Verniers, 1983). In the Orneau valley a similar volcaniclastic layer occurs. The top is located 20 meters below the top of the Fallais Formation and is a few meters thick (Herbosch *et al.*, 2002). In the Thisnes valley a volcaniclastic rock occurs, the “Monstreux porphyroid”, with an unknown thickness. The top is located 20 meters below the top of the Fallais Formation (Verniers *et al.*, 2002b). No biostratigraphical information is available for the volcaniclastic layer in the Orneau valley; these in the Thisnes valley is placed in the upper Telychian (Verniers *et al.*, 2002b). Due to the lack of sufficient biostratigraphical information it is not clear if the volcaniclastic layer at the top of the Fallais Formation present in the Mehaigne, Orneau and Thisnes valley belong to same stratigraphic level.

The Naninne Formation, of the upper Telychian to Wenlock, consists of a quite uniformly lithology: dark grey, finely laminated mudstone, known as laminated hemipelagites. Beds of green, grey-green, green-grey to grey compact mudstone of multiple meters occur together with beds of red mudstone at a certain level. Unfortunately these compact mudstone cannot be located exactly in the chronostratigraphy and we assume that multiple horizons of these compact mudstone occur in the Wenlock. These changes of dark grey, finely laminated mudstone to levels with green to grey, compact mudstone are probably the result of a change in the amount of oxygen in the water column. The dark grey, finely laminated mudstone are deposited in an anoxic environment; the green to grey, compact mudstone are deposited in an environment containing more oxygen.
The fine lamination present in the laminated hemipelagites consists of black laminae. These black laminae are probably the result of planktonic blooms as indicated by Dimberline *et al.* (1990). Centimetric grey to dark grey compact mudstone occur in the succession of the Naninne Formation. They were deposited in anoxic conditions and probably represent periods where no planktonic blooms occur.

The sediments of the Thimensart Formation of the Gorstian indicate a shift to more oxic conditions. The sediments do not contain laminated hemipelagites and more compact layers occur. Although a lamination is still present in many cases. A mixed fauna is present with graptolites, brachiopods, trilobites, crinoids, orthocone nautiloids, conularia and ostracods. The Thimensart Formation can be correlated with the Ronquières Formation of the Brabant Massif that is deposited on the slope as turbidites and laminated hemipelagites. In the Ronquières Formation graptolites are found indicating the *nilssoni*, *scanicus* and possibly *tumescens* Biozones (Rickards, pers. comm. in Louwye *et al.*, 1984 & Van Grootel, 1984) of the Gorstian. The Ronquières Formation contains six (possibly seven) metabentonite levels (Louwye *et al.*, 1992; Verniers *et al.*, 1992) and are interpreted as marine fall-out deposits resulting from highly explosive volcanic activity. The source has to be searched on a distance of several hundred kilometers and has no relation to volcanic activity in the Brabant Massif (Van den haute in Louwye *et al.*, 1992). In the Thimensart Formation in the Condroz Inlier no volcaniclastic layers are found.

Not so much information is available of the Colibeau Formation deposited during the upper Ludlow. Hence no information can be given about the depositional environment and the evolution of the basin from the lower Ludlow to the upper Ludlow.

The Longues Royes and Moncheret Formation, present in the westernmost part of the Condroz Inlier, are deposited in the Ludlow-Pridoli. These two formations are not found in the central Condroz Inlier. The exact tectonically context of these two formations is not known and it is not clear if they belong to the central Condroz Inlier. The deposition area is not known. They are most probably deposited on the shelf in oxic conditions but indicating the position on the shelf is not possible.

Turbiditic sedimentation is present until the lowermost Lochkovian in the Brabant Massif.

4. Other observations

4.1. Red mudstone

Marine red mudstone occurs in multiple beds of the Neuville-sous-Huy Formation starting in the *griestoniensis* Biozone up to the lower part of the *spiralis* Biozone. They are less than 1 millimeter thick, millimetric, centimetric to decimetric but one level is 152 centimeters thick. This is displayed in the sections of Neuville-sous-Huy: Parc de la Neuville, ravine 700 m east of Parc de la Neuville and ravine 1200 m east of Parc de la Neuville. In the Naninne Formation a horizon with multiple beds of red mudstone, 1-1.5 m thick, is observed, in the section Hautes Calenges, but the chronostratigraphically position is unknown. Graptolites of the *rigidus* Biozone are found below the unit of red mudstone (Manil & Ubaghs, 1940). In the Thimensart Formation one level of red mudstone is found 4 millimeters thick in the section of Neuville-sous-Huy, southern part of Parc de la Neuville. Graptolite levels indicate the presence of the *scanicus* Biozone. Hence red mudstone occurs at three stratigraphic levels of the Condroz Inlier. This is contrasting to the Brabant Massif where only one level of red mudstone is described for the whole Silurian. This level is 11 meters thick, described as purplish mudstone, and occurs above a volcaniclastic layer, the “Monstreux porphyroid” (Verniers *et al.*, 2002b) in the Fallais Formation. Above the purple mudstone 9 meters of greenish mudstone and slate occurs before the base of the Corroy Formation is reached. The purple mudstone is placed in the upper Telychian. Hence there is not only a thickness difference between the red mudstone of the Brabant Massif and these occurring in the Condroz Inlier. The red mudstone of the Brabant Massif occurs also at a different stratigraphic level.

The origin of the red colour in the mudstone is still in debate and not so many models are proposed. Ziegler & McKerrow (1975) linked their occurrence to four circumstances that needs to prevail: (1) transgression; (2) high rates of sedimentation; (3) a quiet outer shelf and deeper marine environments; (4) availability of a suitably oxidized source area. Loydell (1998) examined the occurrence of marine red beds of the Telychian in eastern Avalonia, Scotland and Ireland in relation to sea-level changes. He observed that red mudstone occurs predominantly in a period of lower sea-level in comparison with prior and subsequent higher sea-levels of the late *crispus*-early *griestoniensis* Biozones and *spiralis*-early *lapworthi* Biozones (see fig. III.3.2.). The climatic conditions during the late *crispus*-early *griestoniensis* interval induced a high sea-level and were favorable for a red colouring of the rocks in tropical and subtropical latitudes. During the late *griestoniensis*-*crenulata* interval a minor regression resulted in the transport of this weathered material in the marine environment. Only in some quieter, outer shelf or deeper water palaeoenvironments the red colour is retained. On the other places the iron was reduced and the colouration altered. During the subsequent sea-level rise of the *spiralis*-early *lapworthi* interval graptolitic muds are deposited. After that interval sea-level fall is sudden and of considerable magnitude. The red colour did not survive the collective processes of transport, deposition and diagenesis. Ziegler & McKerrow (1975) suggested a transgression but the model of Loydell (1998) contradicts this hypothesis with a minor regression. The model of Loydell (1998) confirms the high sedimentation rates that would be unusual during transgression according to him. McLaughlin *et al.* (2012) observed red mudstone in the Appalachian Foreland Basin that was deposited very slowly (less than 1.5 cm/k.y. near the basin centre vs. more than 15 cm/k.y. for rocks of the same age in the Welsh Basin (Ziegler *et al.*, 1968a, 1968b).

We observed red mudstone in the interval of the *griestoniensis*-lower part *spiralis* hence not completely overlapping with the interval as indicated by Loydell (1998). The chronostratigraphic position of the red mudstone observed in the section Hautes Calenges is unknown and hence cannot be tested. The 4 mm thick level of red mudstone occurs in the middle Gorstian to the lower part of the upper Gorstian. This interval can be correlated with the highest sea-level during the Gorstian (see fig. III.2.1). Hence not confirming the model of Loydell (1998).

The absence of red mudstone levels in the Brabant Massif is most probably due to the effect that deposition took place on the slope not favorable for the generation of red mudstone. The only red mudstone level that occurs in the Brabant Massif with underlying and covering turbidite deposits indicate that most probably this level is deposited as a turbidite.

The red colour in the mudstone comes from ferric iron indicating oxidation. The red mudstone is bounded to certain beds and follows purely the bedding. In the upper part of the Neuville-sous-Huy Formation several horizons are found with coarser and finer mudstone. The red mudstone is only found in the finer parts. When the facies becomes coarser no red mudstone is found. The occurrence of red mudstone only in the finer parts of the section indicates that a certain environment needs to prevail first where deposition of fine mudstone is taken place. One sample of the section of Neuville-sous-Huy, ravine 700 m east, JM 10-52, is a red mudstone. This sample has been palynologically treated and almost no organic matter is left in that sample, indicating that the organic matter is completely oxidized or it was not present during deposition. Red mudstone levels occur always in between green to greenish mudstone. The green colour in the mudstone comes most probably from ferrous iron within the lattices of illite and chlorite. In these green mudstone levels dark grey mudstone can occur but never with underlying or covering red mudstone in direct contact. The red mudstone of the Condroz Inlier is deposited on the deep shelf.

Organic matter is a reducing agent and transforms ferric iron to ferrous iron. The colour changes of red, green and dark grey can be searched in the presence/absence of organic matter but also if the water column is oxidizing or reducing and hence respectively oxic or more anoxic. Hence the colour changes can be linked to oxic intervals and intervals with less oxygen. The red – green – dark grey mudstone indicates a change of the environment of oxic to an environment containing less oxygen. However the rate of primary productivity, and hence supplying nutrients, provide a significant role in the production of organic matter acting as a reducing agent.

4.2. Chitinozoan occurrence

	Cingulochitina spp.	total chitinozoans	percentage of *Cingulochitina* spp.
Ronquières, Ronquières Formation (Verniers *et al.*, 2002b), Brabant Massif			
JV97005	67	130	51,54
JV97007	86	99	86,87
JV97006	14	33	42,42
Pl197.40	76	87	87,36
Pl169.30	23	28	82,14
Pl163.00	3	25	12,00
Pl153.80	1	19	5,26
Pl148.60	13	46	28,26
Pl129.50	12	15	80,00
Pl126.00	12	24	50,00
Pl113.00	7	11	63,64
Pl90.50	0	6	0,00
Pl70.50	0	17	0,00
Pl61.50	18	32	56,25
Pl41.00	14	20	70,00
Pl31.40	0	5	0,00
Pl15.00	268	273	98,17
MG166.30	772	969	79,67
MG149.80	360	438	82,19
MG131.30	1867	2321	80,44
MG113.30	3	5	60,00
MG95.90	0	55	0,00
MG64.70	12	71	16,90
MG40.10	38	63	60,32
MG18.60	21	34	61,76
MG0.40	3	50	6,00
Thimensart Formation, Neuville-sous-Huy, southern part of Parc de la Neuville, Condroz Inlier			
JD 10-22	1	35	2,86
JD 10-23	1	21	4,76
JD 10-25	1	11	9,09
JD 10-26	4	38	10,53
JD 10-27	1	22	4,55
JD 10-28	2	26	7,69
JD 10-33	1	49	2,04

Table III.4.1. Occurrence of the genus *Cingulochitina* spp. in sediments of the Gorstian. The Ronquières Formation at Ronquières, Brabant Massif (Verniers *et al.*, 2002) in comparison with the Thimensart Formation at Neuville-sous-Huy, southern part of Parc de la Neuville, Condroz Inlier (this study).

The sedimentology of the laminated hemipelagites in the Naninne Formation has an important effect on the preservation, occurrence and abundance of chitinozoans. In many cases the chitinozoans are poorly to very poorly preserved in this lithology and chitinozoan abundance is low in these rocks with the occurrence of barren samples. This is most probably caused by the weathering of the rocks. The laminated hemipelagites are susceptible for weathering and they are found in most cases weathered. The effect of weathering is very clear in the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville. In unit 5 two samples have been taken: JM 08-113 in a slightly weathered rock; JM 09-27 taken stratigraphically 17 cm higher than JM 08-113 but taken at the level of the brooklet with almost no weathering at all. Sample JM 08-113, slightly weathered, has an abundance of 0.19 chitinozoans per gram of rock; sample JM 09-27, almost no weathering, has an abundance of 1.13 chitinozoans per gram of rock. This clearly indicates the effect of weathering on the abundance of the chitinozoans. However weathering has almost no influence on the preservation of the chitinozoans and they are still poorly preserved.

When we compare the chitinozoans of the Gorstian rocks of the section of Neuville-sous-Huy, southern part of Parc de la Neuville with these present in the Ronquières Formation, Ronquières, Brabant Massif (Verniers *et al.*, 2002) a big difference in the amount of specimens of *Cingulochitina* spp. is present. *Cingulochitina* spp. is really dominant in the Ronquières Formation of the Brabant Massif in comparison with the section of Neuville-sous-Huy, southern part of Parc de la Neuville of the Condroz Inlier (see table III.4.1.). The genus occurs in the Condroz Inlier but in the same amount (or even less) as the other genera.

During the Gorstian sediments were deposited in the Brabant Massif on the slope; the sediments of the Condroz Inlier were deposited on the deep shelf. Hence the genus *Cingulochitina* spp. has a preference for deeper environments as indicated by Verniers (1982) in the Mehaigne valley of the Brabant Massif.

PART IV – Conclusion

1. Litho-, bio- and chronostratigraphy

The litho-, bio- and chronostratigraphy of different sections of the middle Katian and the Silurian of the Condroz Inlier and one section in the Brabant Massif are described in detail. The chitinozoan contant of a total of 229 samples have been studied, 203 from the Condroz Inlier and 26 from the Brabant Massif. This allows to determine the stratigraphical position of the rocks outcropping in the sections studied. A total of 101 graptolite-bearing levels have been found, sampled and studied as well as with several levels containing brachiopods, trilobites, nautiloids and possibly Conularia. These fossils provide additional information about the age but also about the palaeoenvironment and the palaeodepth.

The definition of the Fosses Formation is restricted to two members, the Bois de Presles Member and the Faulx-les-Tombes Member. The Tihange Member, formerly representing the upper part of the Fosses Formation, is now raised to the rank of formation because of the lack of macrofossils in the unit and the absence of calcareous admixture; both macrofossils and calcareous admixture is typical of the Fosses Formation. The Tihange Formation consists of a lower part of dark grey mudstone with rusty patches. In the upper part, a coarsening upwards is observed from light grey mudstone to light grey coarse to very coarse mudstone followed by a fining upward to darker coloured mudstone with rusty patches and rare beds of coarser mudstone. A lamination becomes apparent as the sediments become coarser. Brachiopods in the Tihange Formation indicate a Hirnantian age. The foregoing proves for the first time the presence of Hirnantian sediments in the Condroz Inlier.

In the Brabant Massif, the Goutteux Member of the lower part of the Brûtia Formation outcropping in Hennuyères consists of green-grey mudstone with dark grey bioturbations present as fucoids. Here chitinozoans indicate a late Hirnantian age. This is the first time that upper Hirnantian sediments are found in the outcrop area of the Brabant Massif.

The Bonne Espérance Formation of the Condroz Inlier consists of laminated, dark green to dark grey mudstone containing eight centimetric, white clay levels parallel with the bedding of the surrounding rock. These clay levels have possibly a volcaniclastic origin and can be correlated with the volcaniclastic rock of the Nivelles Member, Rhuddanian, of the Brûtia Formation in the Brabant Massif. Up to now the formation was thought to span the *acuminatus* to *vesiculosus* Biozones but our restudy narrows this attribution down to an age bracket from the upper part (?) of the *acuminatus* to the *atavus* Biozone, the latter corresponding to the lower part of the *vesiculosus* Biozone. The presence of *Belonechitina postrobusta* corroborates this attribution. An age of the early to middle Rhuddanian is indicated for the Bonne Espérance Formation.

Up to now, the Génicot Formation was not known to occur in the eastern Condroz Inlier. We discovered the formation in the section Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville, eastern Condroz Inlier. It consists of laminated, grey, coarse to very coarse mudstone up to very fine sandstone with rusty and dark yellow laminae and rusty to dark yellow patches. Higher up grey to dark grey mudstone with rusty patches occurs. The presence of *Spinachitina maennili*, *Conochitina alargada* and *Conochitina malleus* indicates an age of middle Aeronian to early late Aeronian.

A problem concerns the original lithological definition of the Dave Formation based on outcrops occurring at the type localities in Dave and the lithology shown in outcrops in the sections of Neuville-sous-Huy corresponding to the same time slice. The small outcrops at Dave consist of dark grey, slightly greenish, mudstone sometimes slightly coarser, containing small rusty patches and rusty spheroids smaller than 1 mm. This lithology is clearly different from that occurring in Neuville-sous-Huy, known as the Neuville-sous-Huy Formation (see below). Graptolites found by Michot (1932b, 1934) indicated the upper Aeronian to the middle Telychian for the outcrops at Dave. Our chitinozoan data indicate an age of late Early Ordovician to Middle Ordovician, contradicting the graptolite information. Vanmeirhaeghe (2006b) has defined at Dave the Chevreuils Formation, from other outcrops not corresponding to the Dave Formation according to Michot (1932b, 1934), for rocks that, as we found out, compare to those of the Dave Formation. We propose to abandon the Chevreuils Formation and include it in the Dave Formation, but the lithological description, fossils and age attribution of the Chevreuils Formation, as defined by Vanmeirhaeghe (2006b), remains useful. Only a name change takes place from Chevreuils Formation to Dave Formation.

A new formation is created for the lower to middle Telychian: the Neuville-sous-Huy Formation. The lower part consists of grey, green-grey to green compact mudstone alternating with dark grey and green-grey, laminated mudstone; higher up red mudstone appears. In the upper part coarser-grained levels occur, consisting of green, green-grey to grey and dark grey mudstone with intercalations of grey coarser mudstone up to coarse mudstone and very fine sandstone. Red mudstone is only present in the finer-grained parts. Volcaniclastic layers occur in the section of Neuville-sous-Huy. Chitinozoans of the *dolioliformis* and the *longicollis* Biozones are found together with graptolites of the *turriculatus-crispus* and *griestoniensis-crenulata* Biozones. These finds indicate an age of early and middle Telychian. After Rickards (1976), the *crenulata* Biozone has been subdivided into four biozones, all in the Telychian. The lowest Biozone in the former *crenulata* interval is now the newly defined *crenulata* Biozone; this lowest Biozone is present in the Neuville-sous-Formation (middle Telychian).

We propose to abandon the term Jonquoi Formation. The formation was poorly defined and after careful examination in several sections we do not see a difference with the underlying Naninne Formation. The Naninne Formation consists of mainly dark grey, finely laminated mudstone, known as laminated hemipelagites, described for the first time in the Condroz Inlier. The dark grey, finely laminated mudstone is interbedded with centimetric, grey to dark grey, compact mudstone. Beds of green, grey-green, green-grey to grey mudstone of multiple meters occur together with red mudstone as well as one level of limestone nodules. In the lowermost part of the formation at Neuville-sous-Huy, a volcaniclastic layer occurs. In the basal part of the formation *Conochitina acuminata* is found; the earliest occurrence of this chitinozoan dates from the upper Telychian. At the top of the formation *Sphaerochitina lycoperdoides* is present, indicating the upper Homerian. Graptolites belong in our case to the combined *insectus-centrifugus* Biozones and to the *murchisoni*, *riccartonensis*, *rigidus* and *lundgreni* Biozones. The forthgoing Naninne Formation, as defined by us, is of late Telychian to late Homerian age.

The Thimensart Formation consists of compact and laminated, grey, olive green, green-grey to grey-green mudstone, sometimes slightly coarser. One red mudstone bed, 4 mm thick, has been observed in the section Neuville-sous-Huy, Parc de la Neuville along the southern pond. The Thimensart Formation has been dated as Gorstian, based on graptolites of the *nilssoni*, *scanicus* and *tumescens* Biozones. The chitinozoans found in the section Neuville-sous-Huy, Parc de la Neuville along the southern pond indicate the Baltoscandian *Ancyrochitina desmea* Biozone to the lower part of the Baltoscandian *Angochitina elongata* Biozone, corresponding to the middle Gorstian to the lower upper Gorstian.

The Colibeau Formation is poorly known and according to Malaise (1913), Maillieux (1930) and Martin (1969a) contains dark grey to brownish black, coarse-grained mudstone with rare intercalations of clayey sandstone. The brachiopod data indicate that the formation may belong to the upper Ludlow. We could not add to the definition nor discard this poorly defined unit.

In the Puagne Inlier, the Criptia Group remains an enigmatic lithostratigraphical unit. The outcrops in Sart-Eustache, Parc de Sart-Eustache of the Criptia Group consists of (dark) green-grey to grey mudstone. The Criptia Group is certainly younger than the Génicot Formation of the middle Aeronian. This is contradicted by the chitinozoans found in the Criptia Group. The chitinozoans found are hence interpreted as the result of reworking. The sediments of the Puagne Inlier were originally deposited significantly further in comparison with these of the central Condroz Inlier. The Puagne Inlier was brought together with the central Condroz Inlier by Variscan tectonics. Hence the Criptia Group cannot be linked with a lithostratigraphical sequence of the central Condroz Inlier. An age of late Llandovery to perhaps Pridoli is tentatively proposed for the Criptia Group.

In the westernmost part of the Condroz Inlier, two lithostratigraphically units occur: the Longues Royes Formation and the supposedly younger Moncheret Formation. The Longues Royes Formation contains green to grey-green mudstone up to coarse mudstone. An age of Ludlow-Pridoli is proposed based on spores and acritarchs (Steemans, unpublished). The Moncheret Formation contains grey to dark grey and dark green mudstone containing beds of dark grey coarse mudstone to very fine sandstone. An age of Ludlow-Pridoli is proposed based on trilete spores (Steemans, unpublished). Our chitinozoan analysis did not provide new information as the microfossils are too poorly preserved.

2. Evolution of the basin of the Condroz Inlier and the Brabant Massif

Litho- and biostratigraphical data of the Condroz Inlier and the Brabant Massif can be used to sketch the evolution of the basin of the Condroz Inlier and the Brabant Massif from the middle Katian to Silurian. During megasequence 3 deposition of the sediments of the Condroz

Inlier took place on the shelf and most of the time on the deep shelf, but changes in the location of the deposition on the shelf occurred. In the Brabant Massif sedimentation always took place in a deeper environment in comparison with that of the Condroz Inlier. The sedimentation began on the shelf from the middle Katian onwards and continued on a slope environment developed from the Llandovery up to the end of megasequence 3.

Verniers *et al.* (2002) proposed a division of the basin of the Brabant Massif beginning in the middle Llandovery into two areas: a deep shelf environment in the southwestern Brabant Massif (south of the Ronse-Veurne line) and a slope environment with the deposition of turbidites in the outcrop area and in the central and north of the Brabant Massif. In the southwestern Brabant Massif, thin turbidite deposits are described in the Rhuddanian and Aeronian. During the lower Telychian also deposition on the slope is proposed. Sediments from the Wenlock to the lowermost Lochkovian in the southwestern part of the Brabant Massif have also been identified as turbidites indicating a slope environment. In our view not so much difference exists between the areas of the Brabant Massif during the Silurian and we hypothesize that no subdivision took place of the sedimentary basin comprising the southwestern Brabant Massif and the rest of the Brabant Massif.

The deepening of the Brabant basin began already in the upper Katian. From the Llandovery on one observes a gentle increase of the thicknesses of the lithostratigraphical units together with an increase of turbidite deposits. From approximately the upper Telychian on, very thick sediment beds are deposited. We like to place the start of the development of the foreland basin already in the upper Katian when the depositional environment began to deepen. The thickness of the sediment beds gently increases from the Llandovery, with a marked increase from the upper Telychian on.

The collected brachiopod fossils help to establish palaeodepths. In the Condroz Inlier, megasequence 3 starts with the deposits of the Fosses Formation. A deepening trend is observed from the Bois de Presles Member to the Faulx-les-Tombes Member from Benthic Assemblage 4-5 to Benthic Assemblage 5-6 (Sheehan, 1987; Vanmeirhaeghe, 2006b). The covering Tihange Formation, deposited during the Hirnantian, shows a shallower environment with brachiopods indicating Benthic Assemblage 3. The shallower conditions correlate with the known eustatic sea-level drop during the time slice represented.

Sedimentation was most probably continuous during the Silurian in both the Brabant Massif and the Condroz Inlier. However Vanmeirhaeghe (2006b) noted a depositional hiatus in the western Condroz Inlier from the Hirnantian to the lower Aeronian. In the eastern part of the inlier, continuous sedimentation seems to have occurred, but observational hiatuses are present.

Starting from the Neuville-sous-Huy Formation, lower to middle Telychian, changes in the position of the oxic-anoxic front, reflecting changes in the amount of oxygen in the water column through time, can be observed. In the Neuville-sous-Formation, changes in colour are observed from red, green to dark grey representing intervals of oxic to less oxygen in the water column. The Naninne Formation, upper Telychian to uppermost Homerian, consists mainly of dark grey, finely laminated mudstone deposited in anoxic conditions, but intervals of green to grey mudstone in this lithostratigraphical unit represents deposition in oxic conditions. The Thimensart Formation of the Gorstian was deposited during more oxic conditions.

3. Outlook

Detailed fieldwork, with intensive outcrop cleaning, allowed us to construct an up-to-date lithostratigraphical column of the Condroz Inlier. A total of 229 samples were analyzed for their chitinozoan content, 203 from the Condroz Inlier and 26 from the Brabant Massif, as well as 101 graptolite levels all of the Condroz Inlier. The foregoing allowed us to place the lithostratigraphical units in the chronostratigraphy and to construct a basin evolutionary model of the Condroz-Brabant basin during megasequence 3. But our research raises further questions.

The Criptia Group in the Puagne Inlier of the Condroz Inlier is a unit deserving further study both by fieldwork and detailed chitinozoan sampling. It will allow to place the group more exactly in the chronostratigraphy and the relation of this unit with the central Condroz Inlier and the Brabant Massif will become apparent.

The same can be said about the Longues Royes Formation and the Moncheret Formation in the western part of the Condroz Inlier.

The Llandovery of the Brabant Massif is poorly known in the outcrop area. It marks the transition towards the thick sediment beds deposited in the upper Telychian. A study of the lithology, sedimentology, dense chitinozoan sampling and collection of graptolites will allow to better characterize this interval and correlate it with the boreholes through the southwestern part of the Brabant Massif in West Flandres.

Further collecting of graptolites of the sections Neuville-sous-Huy, ravine 700 m east and ravine 1200 m east of Parc de la Neuville, focussing on specific levels, will allow to place various parts of the Neuville-sous-Huy Formation more precisely in the biostratigraphy.

The oxic-anoxic intervals present in the Silurian of the Condroz Inlier need further study. These intervals reflect palaeoenvironmental changes that can be correlated with climatic changes. Those of the Naninne Formation need more focused chitinozoan sampling to place the intervals and palaeoenvironmental changes in the chronostratigraphy.

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Appendices

Appendix 1

Sample localities

1. Tihange

see also fig. II.1.2. for the location of the datum points on the map.

northern datum point: northern intersection of the rue Bonne Espérance and the rue Rouge Lion

western datum point Ruisseau de l'Homme Sauvage: located at northern side, western corner of the outcrop in the small gully

eastern datum point Ruisseau de l'Homme Sauvage: located at the northern side, eastern end of the outcrop in the small gully

Chitinozoan samples

Sample number	Unit	Location
JM 06-45	Vitrival-Bruyère Formation	rue Bonne Espérance, southern flank, 100 m east of the northern datum point
JM 06-46	Vitrival-Bruyère Formation	rue Bonne Espérance, southern flank, 107.9 m east of the northern datum point
JM 08-47	Vitrival-Bruyère Formation	rue Bonne Espérance, southern flank, 115.7 m east of the northern datum point
JM 06-47	Vitrival-Bruyère Formation	rue Bonne Espérance, southern flank, 115.6 m east of the northern datum point
JM 06-48	Vitrival-Bruyère Formation	rue Bonne Espérance, southern flank, 120.3 m east of the northern datum point
JM 08-49	Fosses Formation - Bois de Presles Member	rue Bonne Espérance, southern flank, 120.7 m east of the northern datum point
JM 06-30	Fosses Formation - Bois de Presles Member	rue Bonne Espérance, southern flank, 121 m east of the northern datum point
JM 08-48	Fosses Formation - Bois de Presles Member	rue Bonne Espérance, southern flank, 121.3 m east of the northern datum point
JM 06-29	Fosses Formation - Bois de Presles Member	rue Bonne Espérance, southern flank, 121 m east of the northern datum point
JM 06-51	Fosses Formation - Faulx-les-Tombes Member	rue Bonne Espérance, southern flank, 158.3 m east to southeast of the northern datum point
JM 06-52	Fosses Formation - Faulx-les-Tombes Member	rue Bonne Espérance, southern flank, 159 m east to southeast of the northern datum point
JM 06-54	Tihange Formation - lower	rue Bonne Espérance, southern flank, 162.3 m east to southeast of the northern datum point

	part	
JM 08-61	Tihange Formation - lower part	rue Bonne Espérance, southern flank, 163.3 m east to southeast of the northern datum point
JM 06-56	Tihange Formation - upper part	rue Bonne Espérance, southern flank, 173.7 m east to southeast of the northern datum point
JM 06-57	Tihange Formation - upper part	rue Bonne Espérance, southern flank, 177.1 m east to southeast of the northern datum point
JM 08-63	Tihange Formation - upper part	rue Bonne Espérance, southern flank, 177.8 m east to southeast of the northern datum point
JM 06-58	Tihange Formation - upper part	rue Bonne Espérance, southern flank, 181 m east to southeast of the northern datum point
JM 06-59	Bonne Espérance Formation	rue Bonne Espérance, southern flank, 183.9 m east to southeast of the northern datum point
JM 06-60	Bonne Espérance Formation	rue Bonne Espérance, southern flank, 184.2 m east to southeast of the northern datum point
JM 08-50	Bonne Espérance Formation	rue Bonne Espérance, southern flank, 186.3 m east to southeast of the northern datum point
JM 06-61	Bonne Espérance Formation	rue Bonne Espérance, southern flank, 186.5 m east to southeast of the northern datum point
JM 06-62	Bonne Espérance Formation	rue Bonne Espérance, southern flank, 188 m east to southeast of the northern datum point
JM 06-63	Bonne Espérance Formation	rue Bonne Espérance, southern flank, 190.9 m east to southeast of the northern datum point
JM 06-65	Unnamed	rue Bonne Espérance, northern flank, just southeast of the southern end of the limestone wall
JM 06-66	Unnamed	rue Bonne Espérance, northern flank, 6 m southeast of the southern end of the limestone wall
JM 06-39	Fosses Formation - Faulx-les-Tombes Member	rue Rouge Lion, western flank, 74 m southeast of the northern datum point
JM 06-37	Tihange Formation - lower part	rue Rouge Lion, western flank, 77.7 m southeast of the northern datum point
JM 06-36	Tihange Formation - upper part	rue Rouge Lion, western flank, 78.5 m southeast of the northern datum point
JM 06-35	Tihange Formation - upper part	rue Rouge Lion, western flank, 81.9 m southeast of the northern datum point
JM 08-44	Tihange Formation - upper part	rue Rouge Lion, western flank, 82.6 m southeast of the northern datum point
JM 06-33	Tihange Formation - upper	rue Rouge Lion, western flank, 89.6 m southeast of the northern datum point

	part	
JM 06-31	Tihange Formation - upper part	rue Rouge Lion, eastern flank, 95.1 m southeast of the northern datum point
JM 07-20	Bonne Espérance Formation	rue Rouge Lion, western flank, 95.2 m southeast of the northern datum point
JM 08-40	Bonne Espérance Formation	rue Rouge Lion, western flank, 96 m southeast of the northern datum point
JM 08-52	Fosses Formation - Faulx-les-Tombes Member	Ruisseau de l'Homme Sauvage, 6.1 m northwest of the eastern datum point Ruisseau de l'Homme Sauvage
JM 06-43	Fosses Formation - Faulx-les-Tombes Member	Ruisseau de l'Homme Sauvage, approximately at the western datum point Ruisseau de l'Homme Sauvage
JM 07-13	Fosses Formation - Faulx-les-Tombes Member	Ruisseau de l'Homme Sauvage, 2.7 m southeast of the western datum point Ruisseau de l'Homme Sauvage
JM 06-44	Tihange Formation - lower part	Ruisseau de l'Homme Sauvage, 6.7 m southeast of the western datum point Ruisseau de l'Homme Sauvage
JM 07-15	Tihange Formation - lower part	Ruisseau de l'Homme Sauvage, 20.6 m southeast of the western datum point Ruisseau de l'Homme Sauvage
JM 07-16	Tihange Formation - lower part	Ruisseau de l'Homme Sauvage, 27.6 m southeast of the western datum point Ruisseau de l'Homme Sauvage
JM 07-10	Tihange Formation - upper part	Ruisseau de l'Homme Sauvage, 31.9 m southeast of the western datum point Ruisseau de l'Homme Sauvage
JM 07-17	Tihange Formation - upper part	Ruisseau de l'Homme Sauvage, 33.6 m southeast of the western datum point Ruisseau de l'Homme Sauvage
JM 06-71	Fosses Formation - Faulx-les-Tombes Member	Valley of the ruisseau Sainte-Marguerite, 128.8 m southeast of the rue du Centre along the path

Macrofossils

Sample number	Unit	Macrofossils + location
JM 07-18	Tihange Formation - upper part	Brachiopods; rue Rouge Lion, western flank, 87.3 m southeast of the northern datum point
JM 07-19	Tihange Formation - upper part	Brachiopods + trilobites; rue Rouge Lion, western flank, 86.3 m southeast of the northern datum point
JM 06-07	Bonne Espérance Formation	Graptolites; rue Rouge Lion, eastern flank, 95.8 m southeast of the northern datum point
JM 06-09	Bonne Espérance Formation	Graptolites; rue Rouge Lion, eastern flank, 95.8 m southeast of the northern datum point

JM 06-15	Bonne Espérance Formation	Graptolites; rue Bonne Espérance, southern flank, 183.2 m east to southeast of the northern datum point
JM 06-11	Bonne Espérance Formation	Graptolites; rue Bonne Espérance, southern flank, 184.4 m east to southeast of the northern datum point
JM 06-16bis	Bonne Espérance Formation	Graptolites; rue Bonne Espérance, southern flank, 185.1 m east to southeast of the northern datum point
JM 06-12	Bonne Espérance Formation	Graptolites; rue Bonne Espérance, southern flank, 185.5 m east to southeast of the northern datum point
JM 06-70	Bonne Espérance Formation	Graptolites; rue Bonne Espérance, southern flank, 185.9 m east to southeast of the northern datum point
JM 06-67	Bonne Espérance Formation	Graptolites; rue Bonne Espérance, southern flank, 187 m east to southeast of the northern datum point
JM 06-26	Bonne Espérance Formation	Graptolites; rue Bonne Espérance, southern flank, 193.2 m east to southeast of the northern datum point
JM 06-25	Bonne Espérance Formation	Graptolites; rue Bonne Espérance, southern flank, 195.9 m east to southeast of the northern datum point

2. Hennuyères

Chitinozoan samples

Sample number	Unit	Location
SE 10-89	Madot Formation	Section 1; 2.3 m southwards of the northern end of outcrop G
SE 10-88	Madot Formation	Section 1; 1.1 m southwards of the northern end of outcrop G
SE 10-87	Madot Formation	Section 1; 9.5 m southwards of the northern end of outcrop D
SE 10-86	Madot Formation	Section 1; southernmost end of outcrop A
SE 10-96	Madot Formation	Section 1; 1.2 m southwards of the northern end of outcrop B
SE 10-90	Madot Formation	Section 2; K24.4733
SE 10-98	Madot Formation	Section 2; K24.5345
SE 10-99	Madot Formation	Section 2; K24.5367
SE 10-94	Madot Formation	Section 2; K24.5345
SE 10-95	Madot Formation	Section 2; K24.5356
SE 10-93	Madot Formation	Section 2; K24.5423
SE 10-38	Brutia Formation	Section 3; 11.5 m northwards of the southern end of outcrop A
SE 10-39	Brutia Formation	Section 3; 10 m northwards of the southern end of outcrop A
SE 10-40	Brutia Formation	Section 3; 8.5 m northwards of the southern end of outcrop A
SE 10-41	Brutia Formation	Section 3; 8 m northwards of the southern end of outcrop A
SE 10-42	Brutia Formation	Section 3; 5.5 m northwards of the southern end of outcrop A
SE 10-43	Brutia Formation	Section 3; 2.25 m northwards of the southern end of outcrop A

SE 10-44	Brutia Formation	Section 3; 1 m northwards of the southern end of outcrop A
SE 10-45	Brutia Formation	Section 3; 5.4 m northeastwards of the southern end of outcrop B
SE 10-46	Brutia Formation	Section 3; 1.4 m northeastwards of the southern end of outcrop B
SE 10-97	Brutia Formation	Section 3; 4.4 m southwestwards of the northern end of outcrop C
SE 10-92	Brutia Formation	Section 4; 2 m eastwards from the westernmost outcrop side of the quarry
SE 10-91	Brutia Formation	Section 4; 2.3 m eastwards from the westernmost outcrop side of the quarry
SE 10-47	Brutia Formation	Section 5; 0.5 m northwestwards from the southern end of outcrop B
SE 10-48	Brutia Formation	Section 5; 2.6 m northwestwards from the southern end of outcrop B
SE 10-49	Brutia Formation	Section 5; 3.8 m northwestwards from the southern end of outcrop D

3. Neuville-sous-Huy, northern part Parc de la Neuville

The location of several points (created to help with the construction of the map) is indicated on fig. A1.1

Chitinozoan samples

Sample number	Outcrop	Location
JM 11-32	1	11.4 m east of N
JM 12-56	2	just below the base of the "arkose"
JM 11-31	3	10.2 m north of the northern edge entrance of the abandoned quarry
JM 12-50	4	in the abandoned quarry, northern part; 1.4 m below the base of the "arkose"
JM 11-22	4	in the abandoned quarry, southern part; approximately 0.3 m above the top of the "arkose"
JM 12-55	4	approximately 2.25 m north of 2N
JM 11-19	5	19 m north of point B
JM 11-21	5	18.4 m north of point B

Macrofossils

Sample number	Outcrop	Macrofossils + Location
JM 11-20	5	Graptolites; 19.1 m north of point B
JM 12-01	5	Graptolites; 18.4 m north of point B

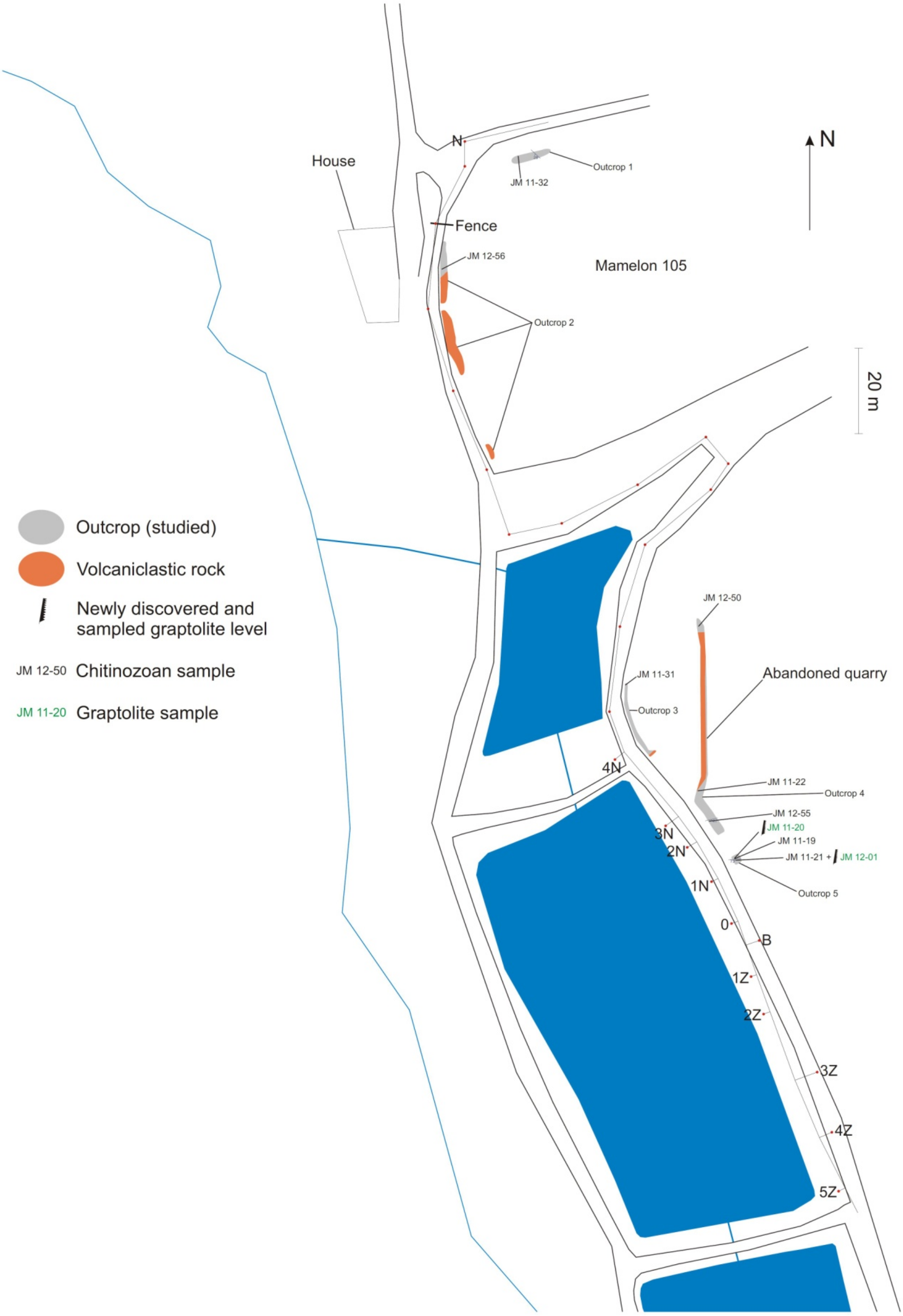

Fig. A1.1. Map of the section northern part of Parc de la Neuville with the location of several points to locate the samples.

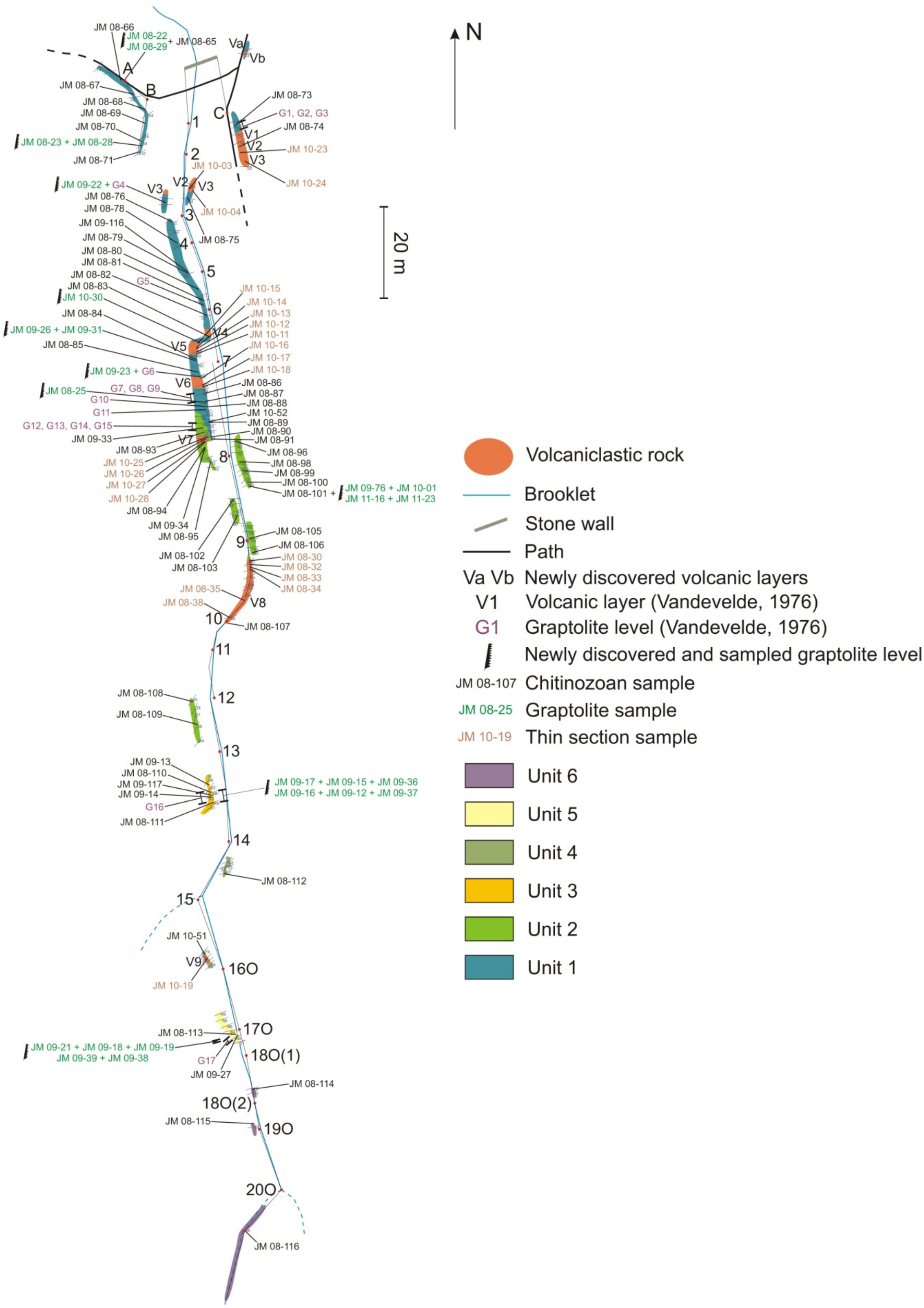

Fig. A1.2. Map of the section Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville with the location of several points to locate the samples.

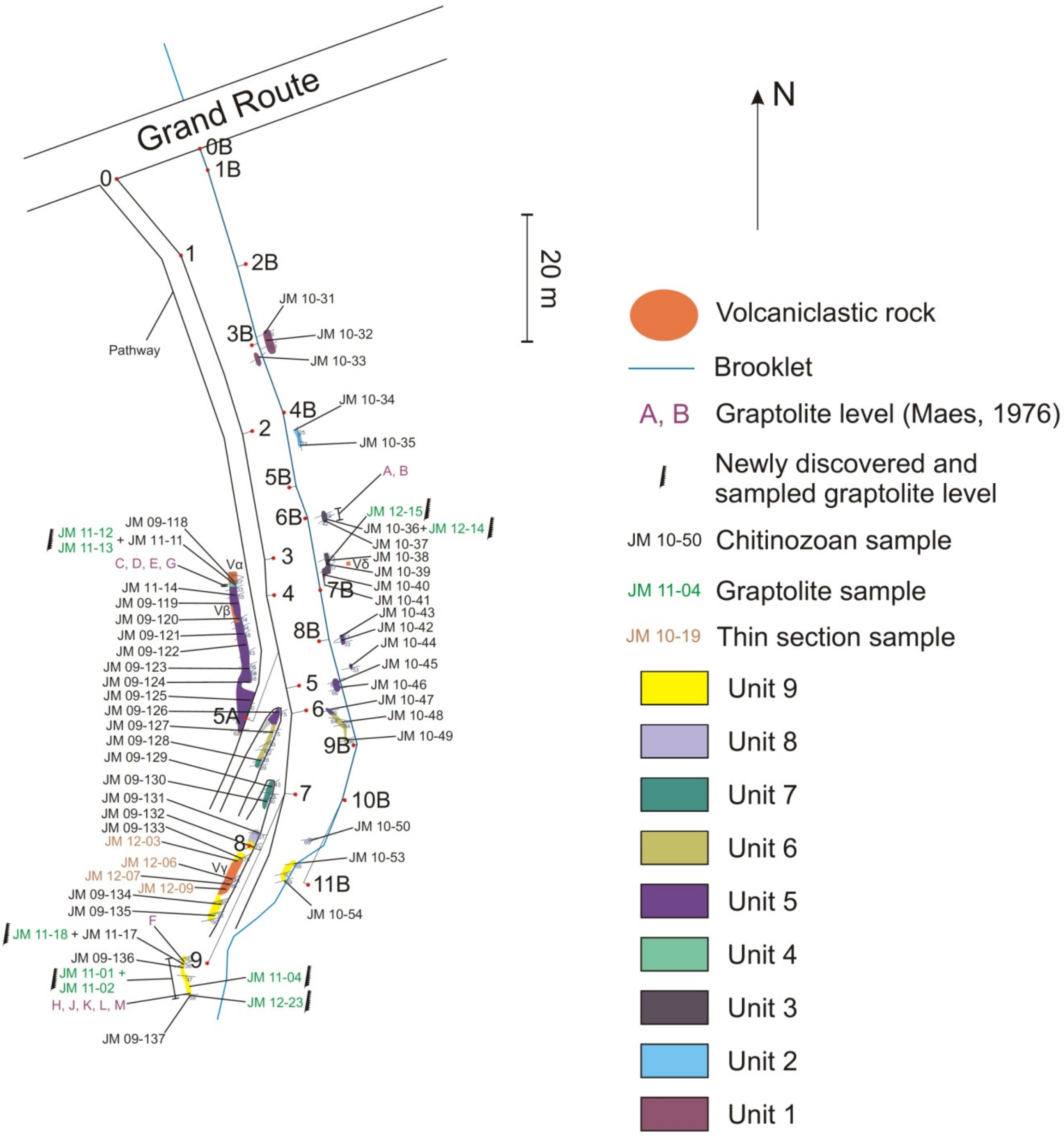

Fig. A1.3. Map of the section Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville with the location of several points to locate the samples

4. Neuville-sous-Huy, southern part Parc de la Neuville

Chitinozoan samples

Sample number	Unit	Location
JD 10-20	a1.1	0.7 m north of the contact between unit a1.1 and unit a1.2
JD 10-21	a1.2	2.7 m south of the contact between unit a1.1 and unit a1.2
JD 10-22	a1.2	3.7 m south of the contact between unit a1.1 and unit a1.2

JD 10-23	a1.3	1.7 m south of the contact between unit a1.2 and unit a1.3
JD 10-24	a1.3	2.5 m south of the contact between unit a1.2 and unit a1.3
JD 10-25	a1.3	2.9 m south of the contact between unit a1.2 and unit a1.3
JD 10-26	a1.3	5.6 m south of the contact between unit a1.2 and unit a1.3
JD 10-27	a2	3.9 m south of the contact between unit a1.3 and unit a2
JD 10-28	a2	6.7 m south of the contact between unit a1.3 and unit a2
JD 10-29	a2	11.2 m south of the contact between unit a1.3 and unit a2
JD 10-30	a2	13.7 m south of the contact between unit a1.3 and unit a2
JD 10-31	a2	16.8 m south of the contact between unit a1.3 and unit a2
JD 10-32	a2	19.1 m south of the contact between unit a1.3 and unit a2
JD 10-33	a2	23.2 m south of the contact between unit a1.3 and unit a2
JD 10-34	a2	24.3 m south of the contact between unit a1.3 and unit a2
JD 10-35	a2	26 m south of the contact between unit a1.3 and unit a2
JD 10-36	b	24.1 m north of the contact between unit b and unit c
JD 10-37	b	21.1 m north of the contact between unit b and unit c
JD 10-38	b	17.4 m north of the contact between unit b and unit c
JD 10-39	b	14.4 m north of the contact between unit b and unit c
JD 10-40	b	13.1 m north of the contact between unit b and unit c
JD 10-41	b	8.3 m north of the contact between unit b and unit c
JD 10-43	b	4.3 m north of the contact between unit b and unit c
JD 10-46	c	9.9 m south of the contact between unit b and unit c
JD 10-47A	c	14.9 m south of the contact between unit b and unit c
JD 10-47B	d	61.1 m south of sample JD 10-47A

Macrofossils

Sample number	Unit	Macrofossils + location
α1	a1.3	Graptolites; 1.3 m south of the contact between unit a1.2 and unit a1.3
γ	a1.3	Graptolites; 1.4 m south of the contact between unit a1.2 and unit a1.3
α2	a1.3	Graptolites; 2 m south of the contact between unit a1.2 and unit a1.3
β1	a1.3	Graptolites, bivalve, crinoids, nautiloids; 2.9 m south of the contact between unit a1.2 and unit a1.3

β2	a1.3	Graptolites; 3.2 m south of the contact between unit a1.2 and unit a1.3
JD 10-16	b	Graptolites; 21.7 m north of the contact between unit b and unit c
JD 10-18	b	Graptolites; 20.2 m north of the contact between unit b and unit c
JD 10-19	b	Graptolites; 5.2 m north of the contact between unit b and unit c
ε	b	Graptolites; 4.9 m north of the contact between unit b and unit c

4. Neuville-sous-Huy, new road 300 m west of Parc de la Neuville

The samples have been located from the datum point indicated on fig. II.4.1.

Chitinozoan samples

Sample number	Unit	Location
JD 10-48	2	116.5 m south of the datum point
JD 10-49	2	104.7 m south of the datum point
JD 10-50	1	74.9 m south of the datum point
JD 10-51	1	65.1 m south of the datum point
JD 10-53	1	29.8 m south of the datum point
JD 10-54	1	9.7 m south of the datum point

Macrofossils

Sample number	Unit	Macrofossils + location
Outcrop 80	1	Graptolites; 29.8 m south of the datum point
Outcrop 78	1	Graptolites; 34.4 m south of the datum point
Outcrop 77	1	Graptolites; 37.4 m south of the datum point
Outcrop 76	1	Graptolites; 40.5 m south of the datum point
Outcrop 74	1	Graptolites; 46.6 m south of the datum point
Outcrop 72	1	Graptolites; 55.2 m south of the datum point
Outcrop 71	1	Graptolites; 59.5 m south of the datum point
Outcrop 70	1	Graptolites, nautiloids; 62.5 m south of the datum point
Outcrop 69	1	Graptolites; 65.5 m south of the datum point
Outcrop 68	1	Graptolites; 69.1 m south of the datum point
Outcrop 67	1	Graptolites; 72.4 m south of the datum point
Outcrop 66	1	Graptolites; 74.9 m south of the datum point
Outcrop 65	1	Graptolites; 77.4 m south of the datum point
Outcrop 64	1	Graptolites; 79.9 m south of the datum point
Outcrop 63	1	Graptolites; 82.2 m south of the datum point
Outcrop 62	1	Graptolites; 84.4 m south of the datum point
Outcrop 61	1	Graptolites, nautiloids; 86.6 m south of the datum point
Outcrop 60	1	Graptolites, nautiloids, sponge spicules; 88.6 m south

		of the datum point

5. Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville

The location of several points (created to help with the construction of the map) is indicated on fig. A1.2.

Chitinozoan samples

Sample number	Unit	Location
JM 08-66	1	0.8 m west of point A; southern flank
JM 08-65	1	0.1 m west of point A; southern flank
JM 08-67	1	3.5 m east of point A; southern flank
JM 08-68	1	2.2 m south of point B
JM 08-69	1	5.2 m south of point B; eastern flank
JM 08-70	1	9.2 m south of point B; eastern flank
JM 08-71	1	11.5 m south of point B; eastern flank
JM 08-73	1	3.1 m south of point C
JM 08-74	1	6.8 m south of point C
JM 08-75	1	4.3 m north of point 3; eastern flank
JM 08-76	1	5.8 m north of point 4; western flank
JM 08-78	1	1 m north of point 4; western flank
JM 09-116	1	1.1 m north of point 5; western flank
JM 08-79	1	0.7 m north of point 5; western flank
JM 08-80	1	3.7 m south of point 5; western flank
JM 08-81	1	2.2 m north of point 6; western flank
JM 08-82	1	1.3 m south of point 6; western flank
JM 08-83	1	6.10 north of point 7; western flank
JM 08-84	1	1.3 m north of point 7; western flank
JM 08-85	1	1.5 m south of point 7; western flank
JM 08-86	1	6.4 m south of point 7; western flank
JM 08-87	1	8.1 m south of point 7; western flank
JM 08-88	1	11.5 m north of point 8; western flank
JM 10-52	1	8 m north of point 8; western flank
JM 08-89	1	8.1 m north of point 8; western flank
JM 08-90	1	4.8 m north of point 8; below subhorizontal fault F1; western flank
JM 08-96	2	3 m north of point 8; eastern flank
JM 08-91	2	4.4 m north of point 8; below subhorizontal fault F1; western flank
JM 08-98	2	1.7 m south of point 8; eastern flank
JM 09-33	2	7 m north of point 8; above subhorizontal fault F1; western flank
JM 08-93	2	6.1 m north of point 8; ; above subhorizontal fault F1; western flank
JM 08-94	2	2.9 m north of point 8; western flank
JM 09-34	2	2.7 m north of point 8; western flank
JM 08-95	2	0.3 m south of point 8; western flank

JM 08-99	2	3.8 m south of point 8; eastern flank
JM 08-100	2	6.4 m south of point 8; eastern flank
JM 08-101	2	7.3 m south of point 8; eastern flank
JM 08-102	2	9.5 m south of point 8; western flank
JM 08-103	2	6 m north of point 9; western flank
JM 08-105	2	0.4 north of point 9; eastern flank
JM 08-106	2	2.8 m south of point 9; eastern flank
JM 08-107	2	0.4 m south of point 10; in the brooklet
JM 08-108	2	at the location of point 12; western flank
JM 08-109	2	5.1 m south of point 12; western flank
JM 09-13	3	6.8 m south of point 13; western flank
JM 08-110	3	8.5 m south of point 13; western flank
JM 09-117	3	8.5 m south of point 13; western flank
JM 09-14	3	8.5 m south of point 13; western flank
JM 08-111	3	10.7 m south of point 13; western flank
JM 08-112	4	6.7 m south of point 14; eastern flank
JM 10-51	4	4.3 m north of point 16O; western flank
JM 08-113	5	0.9 m south of point 17O; western flank
JM 09-27	5	1 m south of point 17O; western flank at the level of the brooklet
JM 08-114	6	3.1 m north of point 18O(2); at the level of the brooklet
JM 08-115	6	1.5 m north of point 19O; western flank
JM 08-116	6	12 m southwest of point 20O; at the level of the brooklet

Macrofossils

Sample number	Unit	Macrofossils + location
JM 08-22 + JM 08-29	1	Graptolites; 0.1 m west of point A; southern flank
JM 08-23 + JM 08-28	1	Graptolites; 10.2 m south of point B; eastern flank
JM 09-22	1	Graptolites; 1.5 m north of point 3; western flank
JM 10-30	1	Graptolites; 4.7 m north of point 7; western flank
JM 09-26	1	Graptolites; 1 m north of point 7; western flank
JM 09-31	1	Graptolites; 1 m north of point 7; western flank
JM 09-23	1	Graptolites; 2.6 m south of point 7; western flank
JM 08-25	1	8.3 m south of point 7; western flank
JM 09-76	2	Graptolites; 7 m south of point 8; eastern flank
JM 10-01 + JM 11-16 + JM 11-23	2	Graptolites; 7.3 m south of point 8; eastern flank
JM 09-17	3	Graptolites; 8.4 m south of point 13; western flank
JM 09-15	3	Graptolites; 1 m north of sample JM 08-111; western flank
JM 09-36	3	Graptolites; 0.6 m north of sample JM 08-111; western flank

JM 09-16	3	Graptolites; 0.3 m north of sample JM 08-111; western flank
JM 09-37	3	Graptolites; 0.1 m south of sample JM 08-111; western flank
JM 09-21	5	Graptolites; 1.1 m south of point 17O; western flank
JM 09-18	5	Graptolites; 1 m south of point 17O; western flank
JM 09-19	5	Graptolites; 1.5 m south of point 17O; western flank
JM 09-39	5	Graptolites; 1.3 m south of point 17O; western flank
JM 09-38	5	Graptolites; 1.3 m south of point 17O; western flank

Thin sections

Sample number	Volcaniclastic layer	Location
JM 10-23	V2	9 m south of point C
JM 10-24	V3	11 m south of point C
JM 10-03	V3	5.9 m north of point 3; eastern flank
JM 10-04	V3	5.7 m north of point 3; eastern flank
JM 10-15	V5	4.7 m north of point 7; western flank
JM 10-14	V5	3.8 m north of point 7; western flank
JM 10-13	V5	3.5 m north of point 7; western flank
JM 10-12	V5	2.8 m north of point 7; western flank
JM 10-11	V5	2.5 m north of point 7; western flank
JM 10-16	V6	3 m south of point 7; western flank
JM 10-17	V6	4.5 m south of point 7; western flank
JM 10-18	V6	4.9 m south of point 7; western flank
JM 10-25	V7	5 m north of point 8; western flank
JM 10-26	V7	4.7 m north of point 8; western flank
JM 10-27	V7	4.1 m north of point 8; western flank
JM 10-28	V7	3.9 m north of point 8; western flank
JM 08-30	V8	4.4 m south of point 9; in the brooklet
JM 08-32	V8	5.2 m south of point 9; in the brooklet
JM 08-33	V8	5.7 m south of point 9; in the brooklet
JM 08-34	V8	6.2 m south of point 9; in the brooklet
JM 08-35	V8	6 m northeast of point 10; in the brooklet
JM 08-38	V8	1.1 m northeast of point 10; in the brooklet
JM 10-19	V9	4.3 m north of point 16O; western flank

6. Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville

The location of several points (created to help with the construction of the map) is indicated on fig. A1.3.

Chitinozoan samples

Sample number	Unit	Location
JM 09-118	4	2.1 m north of point 4

JM 11-11	4	1.9 m north of point 4
JM 11-14	5	0.3 m north of point 4
JM 09-119	5	0.3 m south of point 4
JM 09-120	5	2.7 m south of point 4
JM 09-121	5	5.2 m south of point 4
JM 09-122	5	6.9 m south of point 4
JM 09-123	5	10.7 m south of point 4
JM 09-124	5	5.6 m north of point 5A
JM 09-125	5	3 m north of point 5A; western flank
JM 09-126	5	0.6 m north of point 6; outcrop along the western pathway, sample located on the eastern side
JM 09-127	6	3.2 m south of point 6; outcrop along the western pathway, sample located on the eastern side
JM 09-128	7	7.3 m south of point 6; outcrop along the western pathway, sample located on the eastern side
JM 09-129	7	0.9 m north of point 7; outcrop along the western pathway, sample located on the eastern side
JM 09-130	7	2.3 m south of point 7; outcrop along the western pathway, sample located on the eastern side
JM 09-131	8	2.5 m north of point 8
JM 09-132	9	0.1 m north of point 8
JM 09-133	9	2.4 m south of point 8
JM 09-134	9	9.4 m north of point 9
JM 09-135	9	7.3 m north of point 9
JM 11-17	9	1.7 m south of point 9
JM 09-136	9	2.2 m south of point 9
JM 09-137	9	5.6 m south of point 9
JM 10-31	1	1.3 m north of point 3B; eastern flank brooklet
JM 10-32	1	0.2 m north of point 3B; eastern flank brooklet
JM 10-33	1	2 m south of point 3B; western flank brooklet
JM 10-34	2	3 m south of point 4B; eastern flank brooklet
JM 10-35	2	6.3 m north of point 5B; eastern flank brooklet
JM 10-36	3	0.7 m south of point 6B; eastern flank brooklet
JM 10-37	3	0.8 m south of point 6B; eastern flank brooklet
JM 10-38	3	4.5 m north of point 7B; eastern flank brooklet
JM 10-39	3	3.9 m north of point 7B; eastern flank brooklet
JM 10-40	3	2.4 m north of point 7B; eastern flank brooklet
JM 10-41	3	0.7 m north of point 7B; eastern flank brooklet
JM 10-42	5	0.7 m south of point 8B; eastern flank brooklet
JM 10-43	5	at the level of point 8B; eastern flank brooklet
JM 10-44	5	5 m south of point 8B; eastern flank brooklet
JM 10-45	5	6.9 m south of point 8B; western flank brooklet
JM 10-46	5	7.7 m south of point 8B; western flank brooklet
JM 10-47	5	6.5 m north of point 9B; western flank brooklet
JM 10-48	6	4 m north of point 9B; western flank brooklet
JM 10-49	6?	1.1 m north of point 9B; western flank brooklet
JM 10-50	8	7.9 m south of point 10B; western flank brooklet
JM 10-53	9	1.6 m north of point 11B; western flank brooklet
JM 10-54	9	1.5 m south of point 11B; western flank brooklet

Macrofossils

Sample number	Unit	Macrofossils + location
JM 12-14	3	Graptolites; 0.7 m south of point 6B; eastern flank brooklet
JM 12-15	3	Graptolites; 4.1 m north of point 7B; eastern flank brooklet
JM 11-12	4	Graptolites; 1.9 m north of point 4
JM 11-13	4	Graptolites; 2.3 m north of point 4
JM 11-18	9	Graptolites; 1.7 m south of point 9
JM 11-04	9	Graptolites; 4.5 m south of point 9
JM 12-23	9	Graptolites; 5.6 m south of point 9
JM 11-01	9	Graptolites; approximately 2 m south of point 9
JM 11-02	9	Graptolites; approximately 2.8 m south of point 9

Thin sections

Sample number	Volcaniclastic layer	Location
JM 12-03	Vγ	3.1 m south of point 8
JM 12-06	Vγ	6 m south of point 8
JM 12-07	Vγ	6.9 m south of point 8
JM 12-09	Vγ	7.8 m south of point 8

7. Dave

Chitinozoan samples

Sample number	Location
JM 08-01	Dave, rue Grand Pré; 20.3 m east of the junction of the rue Grand Pré and Fonds de Dave
JM 08-02	Dave, rue de l'École; 0.3 m east of wall of drive
JM 08-03	Dave, pathway located north of rue des Nolettes, 9 m south of fence

8. Naninne

Chitinozoan samples

Sample number	Location
JM 07-21	Naninne, rue des Flawnées; 25.2 m north of rue de la Sapinière
JM 07-22	Naninne, rue des Flawnées; 28.5 m north of rue de la Sapinière

9. Fosses-la-Ville

Chitinozoan samples

<table>
<tr><th>Sample number</th><th>Location</th></tr>
<tr><td>JM 08-15</td><td rowspan="2">Fosses-la-Ville, situated in the outcrop east of the Ruisseau de Thimensart, along a small road in the eastern prolongation of the rue du Try al Hutte; sample JM 08-15 can be situated in the eastern part, sample JM 08-16 can be situated in the western part</td></tr>
<tr><td>JM 08-16</td></tr>
<tr><td>JM 08-14</td><td>Fosses-la-Ville, right bank of the Ruisseau de la Fuette just south of the place called “Le Cheslon”; a small island in the brooklet in front of the outcrop is present</td></tr>
<tr><td>JM 09-09</td><td>Fosses-la-Ville, northern prolongation of the confluence of the Ruisseau de Thimensart and the Ruisseau de la Fuette in a sunken small road; 6.7 m north of the Ruisseau de la Fuette</td></tr>
<tr><td>JM 09-10</td><td>Fosses-la-Ville, northern prolongation of the confluence of the Ruisseau de Thimensart and the Ruisseau de la Fuette in a sunken small road; 17.1 m north of the Ruisseau de la Fuette</td></tr>
</table>

Macrofossils

Sample number	Macrofossils + location
JM 09-07	Graptolites; Fosses-la-Ville, northern prolongation of the confluence of the Ruisseau de Thimensart and the Ruisseau de la Fuette in a sunken small road; 8 m north of the Ruisseau de la Fuette
JM 09-08	Graptolites, brachiopods, trilobites, crinoids; Fosses-la-Ville, northern prolongation of the confluence of the Ruisseau de Thimensart and the Ruisseau de la Fuette in a sunken small road; 8 m north of the Ruisseau de la Fuette
JM 09-11	Graptolites; Fosses-la-Ville, northern prolongation of the confluence of the Ruisseau de Thimensart and the Ruisseau de la Fuette in a sunken small road; 16.6 m north of the Ruisseau de la Fuette

10. Sart-Eustache

see also fig. II.8.5.

Chitinozoan samples

Sample number	Location
JM 08-117	Sart-Eustache, northern part of outcrop 4
JM 08-118	Sart-Eustache, middle part of outcrop 4
JM 08-119	Sart-Eustache, southern part of outcrop 4
JM 08-120	Sart-Eustache, southern part of outcrop 3
JM 08-121	Sart-Eustache, southern part of outcrop 2

11. Bouffioulx

see also fig. II.8.6

Chitinozoan samples

Sample number	Location
JM 09-01	approximately 2 km south of Bouffioulx, reference section Longues Royes Formation situated in the second ravine to the east of la Biesme; samples JM 09-01 to JM 09-05 are taken from north to south
JM 09-02	
JM 09-03	
JM 09-04	
JM 09-05	
JM 09-06	approximately 2 km south of Bouffioulx, reference section Longues Royes Formation situated in the first ravine to the east of la Biesme; outcrop 1

12. Section Hautes Calenges

A datum point has been created to refer the outcrop and the samples. The datum point is located approximately 55 meters northwest of the crossroad of Hautes Calenges and chemin du Herdier and is indicated on fig. II.8.7.

Chitinozoan samples

Sample number	Location
JM 08-18	Le Piroi; 31.3 m northwest of the datum point
JM 08-19	Le Piroi; 70.7 m northwest of the datum point
JM 08-20	Le Piroi; 89.2 m northwest of the datum point
JM 08-21	Le Piroi; 97.3 m northwest of the datum point

Macrofossils

Sample number	Macrofossils + location
JM 08-17	Le Piroi; 17.5 m northwest of the datum point

Appendix 2

List of the recorded chitinozoan species arranged per section / locality

Species	Author	Plate + specimen number
Tihange (chapter II.1)		
Ancyrochitina ellisbayensis?	Soufiane & Achab (2000)	Plate II.1.2., specimen 1
Belonechitina aspera-postrobusta group	Nestor (1980b)	Plate II.1.2., specimen 15
Belonechitina micracantha	Eisenack (1931)	Plate II.1.2., specimen 2
Belonechitina postrobusta	Nestor (1980b)	Plate II.1.2., specimen 14
Belonechitina robusta	Eisenack (1959)	Plate II.1.2., specimen 10
Belonechitina robusta?	Eisenack (1959)	Plate II.1.2., specimen 13
Bursachitina sp. 1	/	Plate II.1.2., specimens 5, 6
Calpichitina lenticularis	Bouché (1965)	Plate II.1.2., specimen 16
Conochitina chydaea	Jenkins (1967)	/
Cyathochitina campanulaeformis	Eisenack (1931)	Plate II.1.2., specimen 4
Cyathochitina cf. *calix*	Eisenack (1931)	Plate II.1.2., specimen 12
Cyathochitina kuckersiana	Eisenack (1934)	/
Cyathochitina sp. 1 sensu Vandenbroucke (2008)	Vandenbroucke (2008)	Plate II.1.2., specimen 11
Desmochitina erinacea	Eisenack (1931)	Plate II.1.2., specimen 7
Desmochitina juglandiformis	Laufeld (1967)	Plate II.1.2., specimen 8
Desmochitina cf. *nodosa*	Eisenack (1931)	Plate II.1.2., specimen 3
Fungochitina spinifera	Eisenack (1962)	Plate II.1.2., specimen 9
Hennuyères (chapter II.2)		
Belonechitina wesenbergensis	Eisenack (1959)	Plate II.2.1., specimen 9
Belonechitina sp. 1	/	Plate II.2.1., specimen 7
Belonechitina cf. sp. 1	/	Plate II.2.2., specimen 6
Conochitina rugata	Nõlvak (2007)	Plate II.2.1., specimen 4, 5
Cyathochitina kuckersiana	Eisenack (1934)	/
Desmochitina erinacea	Eisenack (1931)	Plate II.2.2., specimen 11
Lagenochitina baltica	Eisenack (1931)	Plate II.2.1., specimen 1
Lagenochitina prussica	Eisenack (1931)	Plate II.2.2., specimens 2, 6
Spinachitina oulebsiri	Paris *et al.* (2000)	Plate II.2.1., specimens 3, 4
Spinachitina verniersi	Vandenbroucke (2009)	Plate II.2.1., specimens 14, 15
Neuville-sous-Huy, Parc de la Neuville, northern part (chapter II.3.1.1)		
Angochitina longicollis?	Eisenack (1959)	Plate II.3.1., specimens 3, 4
Eisenackitina causiata	Verniers (1999)	Plate II.3.1., specimens 1, 2
Eisenackitina causiata?	Verniers (1999)	Plate II.3.1., specimens 5, 6
Margachitina margaritana	Eisenack (1937)	Plate II.3.1., specimens 7, 8
Neuville-sous-Huy, Parc de la Neuville, southern part (chapter II.3.1.2)		
Angochitina milleri	Sutherland (1994)	Plate II.3.3., specimens 9-11
Belonechitina lauensis	Laufeld (1974)	Plate II.3.3., specimens 12, 13

Cingulochitina gorstyensis	Sutherland (1994)	Plate II.3.4., specimen 5
Cingulochitina? sp. 1	/	Plate II.3.4., specimen 6
Cingulochitina sp. 2	/	Plate II.3.4., specimens 3, 4
Conochitina claviformis	Eisenack (1931)	Plate II.3.3., specimens 1, 2; Plate II.3.4., specimens 1-3
Conochitina cf. *gutta*	Laufeld (1974)	Plate II.3.4., specimen 9
Conochitina pachycephala	Eisenack (1964)	Plate II.3.2., specimens 10-12
Conochitina cf. *pachycephala*	Eisenack (1964)	Plate II.3.2., specimens 13-15
Conochitina pumilio	Verniers *et al.* (2002b)	Plate II.3.3., specimens 15, 16
Conochitina rudda	Sutherland (1994)	Plate II.3.2., specimens 6-9
Conochitina tuba	Eisenack (1932)	Plate II.3.2., specimen 5
Conochitina aff. *tuba*	Eisenack (1932)	Plate II.3.4., specimens 5-8
Eisenackitina toddingensis	Sutherland (1994)	Plate II.3.2., specimens 2, 3
Salopochitina sp. 1	/	Plate II.3.4., specimens 7-9
Sphaerochitina dubia	Eisenack (1968)	Plate II.3.3., specimens 3-8
Sphaerochitina sp. 1	/	Plate II.3.4., specimen 10
Neuville-sous-Huy, new road 300 m west of Parc de la Neuville (chapter II.4)		
Sphaerochitina dubia	Eisenack (1968)	Plate II.4.1., specimen 1
Sphaerochitina lycoperdoides	Laufeld (1974)	Plate II.4.1., specimen 2
Neuville-sous-Huy, ravine 700 m east of Parc de la Neuville (chapter II.5)		
Angochitina echinata	Eisenack (1931)	Plate II.5.10., specimen 10
Angochitina longicollis	Eisenack (1959)	Plate II.5.8., specimen 15
Belonechitina cavei	Mullins & Loydell (2001)	/
Belonechitina latifrons	Eisenack (1964)	Plate II.5.10., specimen 11
Belonechitina meifodensis	Mullins & Loydell (2001)	/
Belonechitina sp. 1	/	Plate II.5.3., specimens 3, 4
Belonechitina sp. 2	/	Plate II.5.3., specimens 14-16
Bursachitina conica	Mullins & Loydell (2001)	Plate II.5.1., specimens 1-16; Plate II.5.2., specimen 1
Bursachitina aff. *conica*	Mullins & Loydell (2001)	Plate II.5.7., specimens 10-12
Bursachitina sp. 1	/	Plate II.5.6., specimens 5-12
Calpichitina densa	Eisenack (1962)	/
Conochitina acuminata	Eisenack (1959)	Plate II.5.9., specimen 12
Conochitina claviformis	Eisenack (1931)	Plate II.5.9., specimen 15
Conochitina elongata	Taugourdeau (1963)	Plate II.5.3., specimens 9, 10
Conochitina emmastensis	Nestor (1982a)	Plate II.5.7., specimens 1-4
Conochitina cf. *fortis*	Nestor (1982a)	Plate II.5.10., specimen 12
Conochitina leviscapulae	Mullins & Loydell (2001)	Plate II.5.3., specimens 5-8
Conochitina? *leviscapulae*?	Mullins & Loydell (2001)	Plate II.5.6., specimens 13-15
Conochitina mathrafalensis?	Mullins & Loydell (2001)	Plate II.5.8., specimen 11
Conochitina pachycephala	Eisenack (1964)	Plate II.5.10., specimen 7
Conochitina cf.	Eisenack (1964)	Plate II.5.10., specimen 6

pachycephala		
Conochitina praeproboscifera	Nestor (1994)	Plate II.5.8., specimens 12-14
Conochitina proboscifera	Eisenack (1937)	/
Conochitina cf. *proboscifera*	Eisenack (1937)	Plate II.5.9., specimen 13
Cyathochitina campanulaeformis	Eisenack (1931)	Plate II.5.4., specimen 9
Cyathochitina kuckersiana	Eisenack (1934)	Plate II.5.4., specimens 1-8
Eisenackitina aff. *anulifera*	Verniers (1999)	Plate II.5.9., specimen 4
Eisenackitina causiata	Verniers (1999)	Plate II.5.2., specimens 9-16; Plate II.5.3., specimens 1, 2
Eisenackitina dolioliformis	Umnova (1976)	Plate II.5.4., specimens 10-16; Plate II.5.5., specimens 1-10
Eisenackitina dolioliformis?	Umnova (1976)	Plate II.5.2., specimens 2, 3
Eisenackitina cf. *dolioliformis*	Umnova (1976)	Plate II.5.2., specimens 4-8
Eisenackitina inanulifera	Nestor (2005)	Plate II.5.9., specimen 2
Eisenackitina spongiosa	Swire (1990)	Plate II.5.10., specimens 1-5
Eisenackitina sp. 1	/	Plate II.5.5., specimens 11-16; Plate II.5.6., specimens 1-4
Eisenackitina sp. 2	/	Plate II.5.7., specimens 13-16; Plate II.5.8., specimens 1, 2
Lagenochitina sp. 1	/	Plate II.5.8., specimens 5-9
Sphaerochitina lycoperdoides?	Laufeld (1974)	Plate II.5.10., specimen 8
Sphaerochitina sp. 1	/	Plate II.5.7., specimens 5-7
Neuville-sous-Huy, ravine 1200 m east of Parc de la Neuville (chapter II.6)		
Angochitina longicollis	Eisenack (1959)	Plate II.6.1., specimens 6-13
Belonechitina aff. *postrobusta*	Nestor (1980b)	Plate II.6.3., specimen 16
Belonechitina cavei	Mullins & Loydell (2001)	Plate II.6.1., specimens 2, 3
Bursachitina conica	Mullins & Loydell (2001)	Plate II.6.3., specimens 1-2
Bursachitina aff. *conica*	Mullins & Loydell (2001)	Plate II.6.1., specimens 4, 5
Calpichitina densa	Eisenack (1962)	Plate II.6.2., specimens 12-14
Conochitina acuminata	Eisenack (1959)	Plate II.6.2., specimen 15
Conochitina alargada	Cramer (1967)	Plate II.6.4., specimens 9, 10
Conochitina candoris	Van Grootel (1990)	Plate II.6.3., specimens 9, 10
Conochitina emmastensis?	Nestor (1982a)	
Conochitina iklaensis	Nestor (1980a)	Plate II.6.3., specimen 13; Plate II.6.4., specimens 11, 12
Conochitina iklaensis?	Nestor (1980a)	Plate II.6.1., specimen 1
Conochitina malleus	Van Grootel (1990)	Plate II.6.3., specimen 12; Plate II.6.4., specimen 4-8
Conochitina	Nestor (1994)	/

praeproboscifera		
Cyathochitina campanulaeformis	Eisenack (1931)	Plate II.6.4., specimen 14
Cyathochitina caputoi	Da Costa (1971)	Plate II.6.3., specimen 15
Cyathochitina kuckersiana	Eisenack (1934)	Plate II.6.4., specimen 13
Cyathochitina sp. 1	/	Plate II.6.4., specimens 15, 16
Eisenackitina causiata	Verniers (1999)	Plate II.6.2., specimens 6-11
Eisenackitina dolioliformis	Umnova (1976)	Plate II.6.3., specimen 11
Eisenackitina aff. *dolioliformis*	Umnova (1976)	/
Eisenackitina aff. *inanulifera*	Nestor (2005)	Plate II.6.2., specimen 4
Ramochitina aff. *angusta*	Nestor (1982b)	Plate II.6.1., specimens 14-16
Ramochitina sp. 1	/	Plate II.6.2., specimens 1-3
Spinachitina maennili	Nestor (1980a)	Plate II.6.4., specimens 1-2
Spinachitina oulebsiri	Paris *et al.* (2000)	Plate II.6.4., specimen 3
Dave Formation, Dave (chapter II.8.1)		
Conochitina chydaea	Jenkins (1967)	Plate II.8.2., specimens 1-4
Cyathochitina cf. *calix*	Eisenack (1931)	Plate II.8.1., specimens 8, 9
Eisenackitina sp. 1	/	Plate II.8.2., specimens 5, 6
Euconochitina vulgaris	Jenkins (1967)	Plate II.8.1., specimens 10-15
Sagenachitina sp. 1	/	Plate II.8.1., specimen 1
Salopochitina? sp. 1	/	Plate II.8.1., specimens 2-7
Naninne Formation, Naninne (chapter II.8.2)		
Conochitina cf. *proboscifera*	Eisenack (1937)	Plate II.8.2., specimen 15
Jonquoi Formation, Fosses-la-Ville (chapter II.8.3)		
Conochitina claviformis?	Eisenack (1931)	Plate II.8.2., specimen 16
Eisenackitina cf. *inanulifera*	Nestor (2005)	Plate II.8.3., specimen 1
Thimensart Formation, Fosses-la-Ville (chapter II.8.4)		
Ancyrochitina cf. *desmea*	Eisenack (1964)	Plate II.8.3., specimen 7
Criptia Group, Sart-Eustache (chapter II.8.5)		
Belonechitina postrobusta	Nestor (1980b)	Plate II.8.2., specimen 7
Conochitina cf. *electa*	Nestor (1980b)	Plate II.8.2., specimen 8
Conochitina cf. *iklaensis*	Nestor (1980a)	Plate II.8.2., specimen 10
Conochitina cf. *leviscapulae*	Mullins & Loydell (2001)	/
Cyathochitina kuckersiana	Eisenack (1934)	Plate II.8.2., specimen 13, 14
Longues Royes Formation, Bouffioulx (chapter II.8.6)		
Conochitina subcyatha?	Nestor (1982)	Plate II.8.3., specimen 10
Cyathochitina sp. 1	/	Plate II.8.3., specimens 11, 12

Curriculum vitae

Curriculum vitae (last update 7 September 2014)

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Student supervision

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2009-2010 Master level Geology, 1st Master Geology (2 students)

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2011-2012 Bachelor level Geology, 3rd Bachelor Geology (1student)

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Dissertation

Mortier, J. 2007. Litho- en biostratigrafie met Chitinozoa van het Boven-Ordovicium tot het Onder-Siluur van Tihange (Condrozstrook, België): invloed van zeespiegelschommelingen op het faciës. M.Sc. thesis, Universiteit Gent, Belgium.

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12th International Palynological Congress and 8th International Organisation of Palaeobotany Conference, 30 August - 5 September 2008, Bonn, Germany.

NFSR Working Group: “Micropaléontologie végétale et Palynologie (MVP)”, PPMB-MVP meeting, Latest developments in Palynology and Palaeobotany; Palaeobotany, Palaeopalynology and Micropalaeontology, University of Liège, 27 November, 2008.

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Challenges for the Planet: Earth Sciences Perspective. Third International Conference Geologica Belgica. Ghent University, Belgium, 14-15 September 2009.

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Siluria Revisited. International Meeting of the International Subcommision on Silurian Stratigraphy. Ludlow, England, 10-15 July 2011.

NFSR Working Group: “Micropaléontologie végétale et Palynologie (MVP)”, PPMB-MVP meeting; Palaeobotany, Palaeopalynology and Micropalaeontology, University of Liège, Belgium, 30 November 2011.

Moving Plates and Melting Icecaps. Processes and Forcing Factors in Geology. Fourth International Geologica Belgica Meeting. Brussels, Belgium, 11-14 September 2012.

Helped with the organisation of the following conferences

Pre-symposium excursion: Brabant Massif and Condroz Inlier (23-24 August 2008): Closing Meeting of the International Geoscience Programme (IGCP) n°503 ‘Ordovician Palaeogeography and Palaeoclimate’ Conference on “Palaeozoic Climates”, Lille, France, 22-31 August 2008.

Challenges for the Planet: Earth Sciences Perspective. Third International Conference Geologica Belgica. Ghent University, Belgium, 14-15 September 2009.

54th Palaeontological Association Annual Meeting, Ghent, Belgium, 17-20 December 2010.